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Cellular Controlled Drone Experiment: Evaluation of Network Requirements

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<p>The cellular and drone technologies have advanced enough to be combined. The modern cellular technologies, especially the Long Term Evolution (LTE), have low latency and high bit rate. Hence, they are sufficient for controlling delay sensitive video enabled drones. Particularly fitting drone type for LTE control is a multicopter with its high payload and long flight time. This thesis briefs on the drones and LTE Quality Of Service (QoS), and explains how to construct an LTE drone.</p> <p>First, the background on the drones and LTE QoS is explained based on literature. Basic knowledge of LTE QoS is then amended with expert interviews describing the status of it in Finland. Next, a hands on project is executed to construct an LTE controlled drone. The LTE is then evaluated as a control method by comparing its performance to the traditional Radio Controller (RC). Finally, the feasibility of an LTE controlled drone is evaluated by performing example 3D LTE coverage measurements.</p> <p>In this thesis, the LTE controlled drone it is proven to be achievable by constructing a working prototype. Next, the suitability of the LTE is observed to be equal to the traditional RC as a control link. Finally, in the 3D LTE coverage measurements, the LTE controlled drone is discovered to be feasible.</p>		
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<p>Matkapuhelinverkkoteknologiat ja droonit ovat molemmat kehittyneet riittävästi, jotta ne voidaan yhdistää. Uusimmissa matkapuhelinverkoissa, erityisesti Long Term Evolution:ssa (LTE), on riittävän alhainen latenssi ja korkea bittinopeus, jotta niillä voidaan ohjata viiveherkkiä videoyhteydellisiä drooneja. Erityisesti LTE ohjattavaksi sopiva droonityyppi on multikopteri, jolla on korkea hyötykuorma ja pitkä lentoaika. Tämä diplomityö esittelee droonien ja LTE laatuparametrien (QoS) taustaa, ja ohjeistaa kuinka LTE droonin voi rakentaa.</p> <p>Ensiksi taustoitetaan drooneja ja LTE laatuparametreja kirjallisuuskatsauksen perusteella. Sen jälkeen LTE laatuparametrien tietoutta syvennetään käyttäen asiantuntijahaastatteluja, jotka käsittelevät laatuparametrien käyttöastetta ja tilannetta Suomessa. Seuraavaksi kerrotaan, miten voidaan rakentaa LTE:n yli ohjattu drooni. Sitten LTE-yhteyttä arvioidaan ohjausyhteytenä verraten sen toimivuutta perinteiseen radio-ohjaimeen. Lopuksi LTE droonin käytännöllisyyttä arvioidaan kokeilemalla 3D LTE-kuuluvuuskartoituksia.</p> <p>Tässä työssä todistetaan ensiksi LTE:n yli ohjattu drooni mahdolliseksi rakentaa. Sitten todetaan LTE:n sopivan ohjausyhteydeksi yhtä hyvin, kuin perinteisen radio-ohjaimen. Lopuksi todistetaan lte droonin käyttökelpoisuus 3D LTE-kuuluvuuskartoituksen avulla.</p>		
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List of Abbreviations

3D	Three Dimensional
3GPP	3rd Generation Partnership Project
ARP	Allocation and Retention Priority
BEC	Battery Eliminator Circuit
BER	Bit Error Rate
BVLOS	Beyond Visual Line of Sight
dB	Decibel
dBm	Decibel-milliwatts
EASA	European Aviation Safety Agency
ESC	Electronic Speed Control
FAA	Federal Arbitration Act
FC	Flight Controller
FPV	First Person View
GBR	Guaranteed Bit Rate
GPIO	Generic Purpose Input/Output
GCS	Ground Control Stations
GPS	Global Positioning System
GSM	Global System for Mobile Communications
LTE	Long Term Evolution
MBR	Maximum Bit Rate
PC	Personal Computer
PELR	Packet Error Loss Rate
PC	Personal Computer
RC	Radio Control
RPi	Raspberry Pi
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received signal strength indication
SDF	Service Data Flow

TFT	Traffic Flow Template
TS	Technical Specification
QCI	QoS Class Identifier
QoE	Quality of Experience
QoS	Quality of Service
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
VLOS	Visual Line of Sight
VoLTE	Voice over LTE
WLAN	Wireless Local Area Network

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1 Introduction

This chapter briefs on the basic information about this thesis. The First section covers the motivation explaining the reasons for this thesis. The second section explores the purpose of the thesis. The third section introduces the research methods. Finally, the fourth section explains the structure of the thesis.

1.1 Motivation

Radio-controllable (RC) miniature aircrafts and helicopters have been around for a long time now. The original radio control scheme, using Pulse Width Modulation (PWM) over Very High Frequency (VHF) radio bands, is interference sensitive. Only a few oscillation crystals are used with a high probability of many users accessing the same frequency in the same area. Such situation creates a lot of interference, making it impossible to fly. Nowadays, the radio technologies have evolved and the modern schemes tend to use less interference sensitive proprietary schemes, such as the 2.4 GHz Frequency Hopping Spread Spectrum (FHSS) used in the Futaba controllers (Futaba, 2015). A common factor for both schemes is the relatively restricted range. Until now this restriction has not been a major problem, as the traditional RC aircrafts assume the Visual Line of Sight (VLOS).

The development of electronics has changed the simple RC aircraft into an intelligent automated drone, with Global Positioning System (GPS) enabling up-to-date location information. Furthermore, the advent of radio and video camera technologies has made live video streams possible in drones. Combining these technologies enables controlling the drone even Beyond Visual Line Of Sight (BVLOS), which facilitates breaking the range restriction of the old radio schemes. Obviously, one option is the 4th generation cellular network standard, Long Term Evolution (LTE) which has a low latency and high bit rate.

The most versatile RC aircraft type nowadays is the multicopter. It is stable and easy to control, and allows a high payload for cameras and extra equipment. Furthermore, multicopters are getting more popular as hobby toys and in professional use. Thus, a multicopter is a natural choice as the research platform for this thesis.

1.2 Objectives and scope

The first goal of this thesis is to determine if it is possible to use LTE as the connection for the control scheme. At this point, the LTE controllable drones seem to still be non-existent on the market. The next step, providing it is possible to establish the LTE connection, will be evaluating if the LTE channel quality is good enough for controlling a flying drone including low enough latency, jitter and Bit Error Rate. Finally, the LTE control research determines if the bit rate is high enough to stream a live video from the drone, which is required for flying BVLOS?

The second goal is to cover the topics surrounding an LTE controlled multicopter on a higher level. This means questions like what use cases this kind of multicopters could have, does it bring any benefits over the traditional connection schemes and could there be any kind of restrictions on such devices? These restrictions could be, for example, regulations of the country or limitations of the LTE network as whole. Furthermore, two 3D LTE coverage measurements are performed to evaluate the feasibility of the LTE drone as a research platform.

Finally, this thesis maps the Quality of Service (QoS) used in LTE on both technological and economical aspects. Technological aspects cover what kind of effects QoS has on an LTE controlled drone, such as if some settings make it worse or better and how does it affect the video quality? On the economical aspect, interviews are used to answer questions like how is QoS being used nowadays, is there interest on it and would it be used in the future?

1.3 Research method

The main research problem of this thesis is to find a way to build the connection to control the multicopter over LTE. This is done by searching for an applicable multicopter with enough capability to easily switch the radio connection to LTE and then trying to construct it. After the multicopter is constructed and the control link is working, the multicopter is flown over the LTE connection on a local test network. This is used to evaluate the usability of LTE network. It will be evaluated on the subjective personal experience on how well the multicopter reacts to the controls, and secondarily by measurements of the network parameters, like latency and bit rate of the connection. This data is then compared to the traditional de facto control scheme which uses a proprietary radio connection.

Finally for the QoS research, literature review is used to figure out what kind of effects specific QoS classes could have compared to the non-configured network. QoS business cases are covered by interviewing professionals on different fields to get a good grasp of the topic as whole. These include professors of the telecom field and technical managers of telecom and other companies.

1.4 Structure of thesis

This thesis is structured as follows. In the first chapter the main ideas of the thesis are introduced. Next, in the Chapter 2, information about drones, such as multicopters, is delivered by explaining how the terms are defined and what their main properties are. In the third chapter the LTE QoS is covered by answering what it is and how it is utilized in Finland nowadays.

Next, the chapter 4 will cover the methods used in this thesis. This will include explaining the steps to make the multicopter controllable over LTE, including the required programs for the measurements. Expected problems that might happen during this thesis are also covered. These include technical problems, like settings not working normally, parts breaking, GPS issues etc. They might also include LTE

related things such as loss of connection. Furthermore, different foreseeable real life situations will be covered, like too strong interference to the signal.

In chapter 5 a use case example for a LTE controlled drone is verified by doing a 3D coverage measurement by using a multicopter. Finally, the conclusion is presented in the chapter 6. There the final results and assessments, considering the possibilities of LTE copters, weaknesses in this thesis and future for the LTE copters and possible continuation from this thesis at Aalto are showed.

An important part is the Appendix which describes a large part of the work done in this thesis by documenting the required steps to build up a working LTE multicopter and usage manual.

2 Drones

In this Chapter the topics related to the drones are covered. The first section explains what the drones are and how have they developed. The second section talks about the different ways to classify drones. The third section covers a specific drone type, multicopters. The fourth section features the multicopter uses and purposes. The fifth section talks about the risks related to the multicopters. And finally the sixth section discusses about the drone regulation.

2.1 Introduction to drones

Drone, Unmanned Aerial Vehicle (UAV), (Friedrich, 2014) Remotely Piloted Aircraft (RPA), many terms can be used for the same thing: “an aircraft without a pilot on board” and controlled either externally or by a computer. These terms are often extended to UA System (UAS) or RPA System (RPAS) to cover everything related to using an UAV, including controllers, Ground Control Stations (GCS) and launching pads. The term UAV includes any kind of unmanned aerial vehicle, even the uncontrolled ones such as missiles. The drone is a subcategory of UAV and narrows the meaning to either autonomous or remotely controlled (RC) aircrafts. Finally the RPA, as stated by its name, includes only the RC aircrafts. (EASA, 2015) On this thesis the term drone is used and chosen as the main term for several reasons. First, it fits on the modern devices which can be used with both, autonomous and RC, schemes interchangeably. Second, it has the longest history since the military use in 30s (Friedrich, 2014). And as last, it is a short and familiar term for people. To emphasize the type and use of the drone, the term multicopter is used for the specific type of drone explained in the Section 2.3 Multicopter, and the term drone is used for any automated or remotely controlled aircraft.

UAVs have been used for over a hundred years now, but the name drone, in the modern sense, became to existence only after 1930s. In the beginning they were used only for target practice, and later in 60s also for the military reconnaissance missions. The beginning of the modern drones with live video cameras is said to have begun in the early 1970s with the surfacing of the ability to send photos to the base. From there drones have developed into the modern military class long distance multipurpose drones, like MQ-1 Predator shown in Figure 1 below, full of sensors and functionality. (Friedrich, 2014)



Figure 1. An MQ-1 Predator military drone (Sustainable Security, 2013)

Furthermore, the technological advancements of military drones have led to the development of the civil drones. Earlier, civilians were flying UAVs in the form of airplane and helicopter models by radio controls with no autonomy on-board. Now the development of technology has made it possible to have autonomous drones at home, extending their use to other fields such as commercial use. The civilian drones are often multicopters which are piloted remotely, but they also have enough intelligence for autonomous flight with live video feed. (Ardupilot Team, 2015)

The shape of a drone can be almost anything, like “fixed wing, rotorcraft, tilt rotor, or airship”(EASA, 2015). By Merriam-Webster (2015) dictionary, a rotorcraft is “an aircraft (as a helicopter) whose lift is derived principally from rotating aerofoils”. Rotorcraft is a bit vague term, as it includes everything gaining lift from rotating aerofoils, including also the specific helicopters. To separate helicopters from the differently working aircrafts using rotors directed upwards only, a term multicopter was invented (Gentile, 2012). Thus, the term multicopter is used in this thesis to emphasize the specific type of the drone used. Other drones types are usually airplanes which are used for reconnaissance and long distance flying, but cannot have as big payload compared to the multicopters.

2.2 Drone classifications

Civilian drones are relatively new phenomena without much of legislation existing yet. On the other hand, to make the legislation, a classification is needed to figure out the different kinds of requirements. The civilian drone classification has not been finished yet and is still a work in progress. This chapter explains the current status of the drone classification.

The first step is to classify drones in a broad and simple way. There has already been one broad classification for drones, military versus civilian. Another broad classification would be piloted versus autonomous (EASA, 2015). However, a more accurate definition seems to be hard to achieve, which can be seen from the amount of classifications listed by NASA (2015), in which they have made a good collection covering many different countries. Some parameters are take-off weight, speed, operational altitude, distance and environment, purpose of use and kinetic energy. The latter is important as it defines the likely damage caused by a collision. The parameters are then used in different combinations with weight being used in almost every classification. One problem on these classifications from the common civilian’s point of view is that the weight classes go only from <25 kg to >150 kg, which are meant for the commercial drones. This is lacking, as it is rare for a hobbyist drone to be over 8 kg, most of them being less than 1 kg. On Table 1 on the next page, a good example of a classification is illustrated and it includes the three most common parameters and considers also the smaller drones. Furthermore, it is good to notice, that only micro and mini classes are likely to be used in civilian use.

Table 1. Example of a military classification (Weibel, 2005)

Class	Mass Range [kg]	Operating Area	Operating Altitudes [m], flight level [FL]
Micro	< 1	Local	< 150
Mini	1 - 14	Local	30 – 3 000
Tactical	14 - 455	Regional	460 – 5 500
Medium altitude	455 – 13 600	Regional / National	5 500 – FL 600
High altitude	455 – 13 600	Regional / National / International	> FL 600
Heavy	> 13 600	National / International	5 500 – FL 450

On the other hand, EASA (2015) has proposed a three category classification based on the risk for the operation of drones. These categories would be ‘Open’ for low risk, ‘Specific’ for medium risk, and ‘Certified’ for high risk operation. The names come from the user requirements with open being free for all, specific meaning more demanding drones and certified requiring a pilot certification. The risks addressed should be the likelihood for collision, to harm people and to damage property. The risk level would then mostly depend “on the energy and complexity of the drone”.

In addition, the military classifications seem to be different from the civilian, which is not surprising considering the operational requirements of the military use. The first way, classification by performance, resembles the civilian classifications. Some of the parameters are the same, like weight, maximum altitude and range. Still, even though these parameters are the same, their values are different (EASA, 2015). For example, the most of civilian classifications define the operational weight of over 150 kg as the biggest weight class, whereas the military classifications define it as over 2000 kg (Maddalon, et al., 2013). Finally, the military applications require a completely different classification which would be ‘Micro aerial vehicles’, ‘Local area support vehicles’, ‘Tactical area support vehicles’ and ‘Theatre area vehicles’ (EASA, 2015).

To summarize, a good legislation requires a good classification and such is hard to define. Different countries and organizations, like military and civilian, have different kinds of approach on the topic and have made different kinds of classifications. And finally, the most common way is to classify by the purpose of use.

2.3 Multicopter

A specific type of drone is the multicopter which this thesis will concentrate on, partly because they are the most interesting civilian drone type nowadays, and partly because the main research tool on this thesis is the LTE multicopter. By Gentile (2012) a multicopter is an aircraft which uses multiple upwards directed rotors and which is controlled by varying the rotor speeds. All of this is controlled by powerful micro-electronics and sensors. Indeed multicopters are a rather new invention in the, as it is hard to build a working multicopter without efficient

electric motors, light and high capacity rechargeable batteries and microcomputers. Out of these three, the most important stepping stone for the advent of multicopter was the invention of Lithium-Polymer batteries which are light and powerful enough for multicopter use. Moreover the development of microprocessors and – chips has played an important role in the automatization required for such copters. In this section the general information on the drones will be explained.

The multicopter can have many different shapes and sizes. Usually the shape depends on the amount of the rotors attached to the ends of the arms positioned symmetrically. The amount of the rotors define the type of the multicopter, most common types being tri- (3), quad- (4), hexa- (6) and octocopter (8). Especially the quadcopter can be divided into many different styles like X, + and H depending on the orientation of the rotors compared to the front of the quadcopter. Also hexa- and octocopters have specially shaped versions with two rotors attached on each arm, making them Y and X shaped. The different layouts and rotor amounts have some differences between. In general, the quadcopters are small, light, cheap to build and easy to fly, and that is why it is the most popular for hobbyists. On the other hand, the often bigger hexa- and octocopters have much more lifting capacity and have redundancy in the motors in case of failure, and are popular for the professional use. The best multicopters for weightlifting are the Y6 and X8 which have a much higher payload compared to the other types (Ardupilot Team, 2015) Some of the different types are shown below in the Figure 2.



Figure 2. From the left to right, tri-, quad- and X octocopter. (Ardupilot Team, 2015)

The multicopters can be different sizes of tens of centimetres to multiple meters. The quadcopter in the middle of Figure 2 has diameter of only 4.5 cm (Estes Rockets, 2015). The common size for a quadcopter seems to be around 50 cm, while the hexacopter used in this thesis is around 90cm. One of the most extreme cases is an 18 rotor human carrying multicopter design VC200 (e-volo, 2015). On the next page, in the Figure 3, the hexacopter used in this thesis is shown.



Figure 3. The multicopter used in this thesis

As can be seen from the figures above, multicopters are built up from all kinds of parts. Some of the important parts are the frame, motors, propellers and batteries. Some other, less visible but as important, parts are the power distribution board, Electronic Speed Controllers (ESC) and of course, the flight controller (FC). The power distribution board is used to distribute the power from the batteries to the motors through the ESCs which are used to synchronise and balance the motors. (Ardupilot Team, 2015) Below in the Figure 4 some of the important parts are shown.



Figure 4. From left to right: ESC (HiModel WebStore, 2015), carbon fibre propellers (Ardupilot Team, 2015) and an electronic motor (FPV.tv, 2014).

Less necessary, but common parts used with multicopters are radio receiver, GPS and gimbal. Traditionally the radio receiver has been a crucial part for multicopters, as there has not been any other way to control it. Nowadays other kind of options, such as automated flying and Wireless Local Area Network

(WLAN), have become available and made it an unnecessary, but not obsolete, part of the multicopter.

GPS which is usually used for the automated flying has become a common part for multicopters. It is used for functions like flying through the waypoints, return home and geofencing. Return home functionality enables the copter to return back to the location where it was started in problem situations, like when the connection to the controller is lost. A simple version of geofencing prevents the multicopter flying too far from the starting point. A more advanced version prevents the multicopter from entering to areas, like airports, specified in advance.

Gimbal is a holder for the camera. It usually has its own motors for stabilization. This means, that the gimbal tries to keep the camera horizon always balanced and remove the vibration created by the moving parts. This is an especially important device for camera multicopters which are supposed to record high quality video or shoot sharp photos. Furthermore, it can sometimes be controlled by another radio controller to change the camera direction independently from the multicopter direction. This way two persons can be used to record high quality movies and camera drives.

Multicopter is an unstable by design as it has many separate motors. Thus it needs a powerful controller and a good program to keep it balanced. To know about the forces affecting, location and the current angle of the multicopter, the FC has lots of sensors on-board. (Gentile, 2012) They include sensors such as gyroscopes to know the tilt, accelerometers to know the inertia, and barometer to measure the altitude of the multicopter. (3D Robotics, 2015) Many differences between FCs exist, with the simplest only stabilizing the multicopter and the most advanced having many different modes and automated flying. Furthermore, most of the FCs can be only used with the traditional RC controller, while some support any kind of optional controller. The optional controller, for example, can be a Nintendo Wii controller using a WLAN or Bluetooth connection. One of the important features of a research multicopter is a high quality black box which records all information during the flight. An example picture of an advanced FC is shown below in Figure 5.



Figure 5. A Flight Controller (3D Robotics, 2015)

Like stated in the multicopter definition earlier, controlling the multicopter happens by the FC changing the rotation speed of the rotors, which creates the required inertias. An important factor to notice with the multicopters is that excluding some special cases, like the tricopter, the rotors are rotating to different directions always in pairs, but still giving lift. This way the copter stays at the same spot or goes up or down when all the rotors are rotating at the same speed. It tilts to specific direction, when all the rotors on one side accelerate and on one side slow down. Rotation (yaw) is created with one of the rotor pairs slowing down, while the other pair speeds up. This creates torque and rotates the craft. (Gentile, 2012)

2.4 Multicopter users and applications

The first party to use the drones was the military. In the beginning they were just used for simple reconnaissance missions and as targets for shooting practice. Later on, after the technologies advanced enough, drones became the war machines the word “drone” brings to mind. The modern military drones are still mainly used for reconnaissance, but now they are also used for straightforward attacks. The amount of the drone attacks is rising and becoming a crucial part of the air warfare. Further, the military has started using multicopters for short distance reconnaissance missions. (Friedrich, 2014) In the future it is possible that drones become the most important tool used in the war.

But the advent of technology has brought drones also available for civilian use. The amount of different use cases is growing fast with the imagination as a limit. For some time now, the radio controlled airplanes and helicopters have been used as amusement for hobbyists. They have also been used somewhat for commercial mapping, agricultural use and video shooting, but their price, instability and low payload has limited their use.

The real change happened with the arrival of multicopters. With the multicopters having the high quality electronics on-board, the stability, easiness and possible payload have grown drastically (Lozano, 2015). This has made them much more approachable for normal people and hobbyists, as the price has been decreasing rapidly and the learning curve is low compared to other drones types such as helicopters and fixed-wing airplanes. Hence, another user group is the hobbyists. They use multicopters for recreational fun just flying around, taking photos or videos of their surroundings. Multicopters are also used for competing in races, so having real drone racing tournaments is possible in the future (FPV Racing, 2015). The racing is done by using specific First Person View (FPV) equipment which gives the pilot a first person view like he was on-board the multicopter.

The third user group is the commercial field. It is already commonplace to use multicopters to shoot high budget movie scenes and beautiful scenery photographs (Amato, 2014). These movie drones might cost tens of thousands (CineDrones, 2015), and have equipment worth of thousands of euros on-board (Red Digital Cinema, 2015). Still they are much cheaper to buy, easier to use and require much less space than a real full-sized helicopter. Furthermore, in Finland electricity

power companies have started using multicopters to map broken power lines (Pölkki, 2014). But a lot of room for new application ideas still exists.



Figure 6. DHL delivery drone (Truong, 2014)

Many of the use cases are still on the drawing board or in the test phase, but many of them are soon going to be possible. A good example is postal companies after they saw the possibility of drones for delivering mail. First it was Amazon developing a quadcopter for such purpose, then Google using fixed-wing planes and then Deutsche Post AG (DHL) made the first regular delivery service with a multicopter shown above in Figure 6 (Hern, 2014). And now Finnish Posti has done collaboration with the verkkokauppa.com to deliver packages to Suomenlinna, even though it was just a couple of days of testing (Posti Oy, 2015). One more way could be using multicopters for warehouse logistics (Ackerman, 2014).

The fourth user group is the emergency services. Firemen are using drones in fire control missions, using live video on the progress from above (Griffith, 2013). And now, as the newest news on the drone field, North Dakota police has gotten permission to use drones as non-lethal weapons, shooting tear gas or Tasers from the air (Garver, 2015). There has also been some research for using multicopters for rescue operations, like locating avalanche victims (Victor Wolfe, 2015) and defibrillator drone delivering fast aid for heart attack patients (Starr, 2014)

As last, multicopters have a great research potential. By Google Scholar they are used for all kind of research, like computer vision and video development, extending cellular networks and collaboration of multiple multicopters.

Common for all of these use cases is that they work either over radio control or over automated waypoints in Visual Line Of Sight (VLOS) distance. As the amount possibilities already with VLOS multicopters are so tremendous, they can be extended even further with the much longer range of LTE drones.

The LTE connection can be used also for other purposes than the controlling. As it will be explained later on, it is possible to get live status information from the drone to the pilot. This connection could also be used two ways sending information, such as geofencing data, to the FC. It could be further developed into an air traffic control system for drones. (Simonite, 2014)

2.5 Multicopter risks

New technological advancements never come without problems, and same applies for the multicopters. Similar problems have existed before, but because of the steep learning curve they have not been so common. The easiness of multicopters has made them popular and common. In addition flying devices are always full of risks. Some of them are purely technical such as the flight controller malfunctioning and the drone escaping from the user (Nicas, 2014). Some are human mistakes or ethical problems, for example, flying around high security locations such as nuclear power stations (Lichfield, 2014). This section covers different kinds of problems related to the drones.

One of the most common problems with hobbyist drones is the already mentioned “fly-away” which means the drone going out of control and flying too far to be recoverable. It is especially problematic, as the fly-aways can occur for multiple reasons such as bad calibration, GPS signal loss and radio signal loss. Such cases have already been numerous (Montgomery, 2014). GPS signal can be lost easily when flying in an area with bad reception or under structures, like a heavy bridge. Radio signal loss can occur when the pilot flies too far away, or the radio receiver breaks. No matter what the reason is, the lost drones can fly anywhere crashing on buildings, aircrafts and humans (EASA, 2015). Even though multicopters commonly have a “return to home” functionality which should make sure the device returns back to the pilot in the case of signal loss, it does not always happen either because the GPS is messed up, or because an obstacle is on the way, like happened to Cade (2014). In other words, the “return to home” functionality is still too simple and should be developed more. Furthermore the motors or related electronics might fail, making a quadcopter to fall uncontrollably. In fact, some solutions already exist for such problem such as parachutes (Drone Trest, 2015). As last, the multicopter might have a power loss, either by technical malfunction such as fire on-board, or just simply running out of battery.

Other big problems brought by multicopters are the misuse and vandalism. They are easy to get, cheap, easy to fly, have high payload and have a camera on-board, which makes them good tools for misuse. Starting from the lighter side, such misuse can happen because of lack of knowledge, for example, by flying nearby airports endangering the airplanes taking off (Villeda, 2015) or flying while being drunk around the White House (Shear & Schmidt, 2015) and painting walls, like in New York City (Michel, 2015). On a bit worrisome side, they can be used by activist movements flying around sensitive areas such as nuclear power stations like mentioned already earlier. Or they can be used for smuggling drugs over the border, like has happened between U.S. and Mexico border (Davis, 2015). These cases do not sound that bad, but it is easy to see how serious problems the

multicopters can create, if they are used for terrorism by attaching bombs on them (Brooks-Pollock, 2014).

No matter what the reason for the drone hitting unintended targets is, it can be imagined what kind of damage a 20 kg device, falling from the sky or hitting a passenger airplane, can do. This has been modelled for example by Weibel and Hansman (2005). And this is why regulation is needed.

2.6 Drone regulation

Traditionally the Radio Controlled (RC) aerial vehicles have not created lots of trouble, as it has not been possible to fly beyond line-of-sight. This is because without the modern camera and telecommunication technologies, the only way to control them has been by seeing them with your own eyes. This has limited the possible flight distance a lot. Fixed-wing airplanes have easily flown out of the range of the controller, and helicopters have been too unstable to fly far away. Furthermore, their lifting capacity has not allowed much of extra equipment on-board. This has made the regulation easy, or even almost unnecessary. Thus the current drone legislation is loose, allowing almost anything with a couple of specific rules.

But now, the rapid development of customer electronics has enabled multicopters. Because of the intelligence in the Flight Controller (FC), they are stable enough to stay at the same spot without human intervention. With GPS they can fly by themselves through the pre-set waypoints, making it possible for the multicopter to fly relatively long distances unattended, with any outer threat closing by unbeknownst to the device. Multicopters having enough lift to carry even heavy payloads such as digital cameras and video cameras have made them a popular tool to shoot videos on top of audiences, which is dangerous. And the latest trend, using first person view (FPV) setups, allows the user to pilot the drone seeing where to fly as long as the radio works with a limited view and information about the surroundings.

The new ways of piloting these aerial vehicles has changed the need for legislation completely. Multicopters are becoming common, the pilot needs almost zero knowledge to fly them, they have lots of sensitive equipment prone for breaking, and they are heavy and have lots of moving parts. This worries the regulators, who are scared and worried for the first risk group, human lives. Furthermore EASA (2015) lists two more risks groups for drones: “mid-air collision with manned aircraft” and “damage to property”. These kinds of worries have created a need for regulating the usage of drones all around the world. FAA (2014) has already started legislating and restricting the use. In China they have already started requiring licenses for the drone pilots (Dahan, 2014). And of course, Trafi (2015a) has already made a draft of the regulation too.

By the drafts around the world, generally the use of drones for delivering packages, flying over audiences, flying nearby airports etc. would be forbidden. Additionally it seems to be common plan that small drones, like toy multicopters and model airplanes, would be allowed to be flown without any licenses for recreational use

(Maddalon, et al., 2013). In the Table 2 FAA (2014) separates recreational use from the non-recreational use. This recreational use would also have strong limitations, like flying distance limited to the visual line of sight, and restricted flying nearby specific areas, like airports or power stations. (FAA, 2014) (EASA, 2015) On the other hand, some special cases have also been made. For example Amazon, amongst already 128 other companies, have gotten an exemption to test the drones for mail delivery (Jansen, 2015).

Table 2. Differences between recreational and commercial use (FAA, 2014)

Hobby or Recreation	Not Hobby or Recreational
Flying a model aircraft at the local model aircraft club.	Receiving money for demonstrating aerobatics with a model aircraft.
Taking photographs with a model aircraft for personal use.	A realtor using a model aircraft to photograph a property that he is trying to sell and using the photos in the property's real estate listing. A person photographing a property or event and selling the photos to someone else.
Using a model aircraft to move a box from point to point without any kind of compensation.	Delivering packages to people for a fee.
Viewing a field to determine whether crops need water when they are grown for personal enjoyment.	Determining whether crops need to be watered that are grown as part of commercial farming operation.

In Finland the aerial vehicle legislation is done by the Finnish Transport Safety Agency, Trafi. Like mentioned already, the current legislation is loose, as the only limitations are 20 kg weight limit, 150 m height limit and a VLOS to the drone as recommendations (Ilmailuhallinto, 2007). This is why the Trafi, after the other legislative organizations like European Aviation Safety Agency (EASA), has started creating a new all covering legislation for the aerial vehicles, also touching up some hobbyist model aircraft rules. The first draft was published by Trafi (2015a). It raised opposition, as the hobbyist could not agree on some of the laws proposals (Kopterit.net, 2014). However, the Trafi is understanding and they are asking for public opinion before the final version, coming in the end of 2015.

The most important part of the first draft is differentiating between the professional and hobbyist use of drones. Professionals fly over audiences and Beyond Visual Line Of Sight (BVLOS), so it makes sense to require more strict rules and higher familiarity with the equipment. On the other hand, hobbyists are using the multicopters on open fields less often compared to professionals.

The draft does not actually affect multicopter hobbyists much, as the biggest change for hobbyists is forbidding anything else than Visual Line Of Sight (VLOS) piloting. The VLOS means that the pilot has to be able to follow the multicopter continuously with his own eyes, instead of devices like cameras, First Person View (FPV) equipment or other person. There has been a growing audience for FPV

flying (FPV Racing, 2015), where the pilot does not have VLOS to the vehicle while wearing the video glasses. Interestingly, the draft does not allow using a spotter for recreational use compared to commercial use, where it is allowed. This forbids the FPV racing completely. Furthermore, multicopters are not allowed to be used above audience. Finally, the draft does not include a requirement for any kind of drone license. (Trafi, 2015a)

The draft affects more on the professionals and is much stricter on them. For example, the pilot needs to be at least 18 years old, the drone has to be registered, it needs to have pilot name and contact details attached, and the pilot needs to keep a log book for every flight done. The Finnish draft does not require a drone piloting license, compared to the American draft by FAA (2014). But the professionals would also need to take good care of the drone, for example going through a status check-up before every lift-off. The VLOS rule affects the professionals too, making the automated waypoint flying forbidden without a temporary license. Compared to the recreational use, in commercial use the use of a spotter is allowed, who must also be over 18 years old. The pilot and spotter must have two separate communication devices available all the time. This restricts the drone use as the most beneficial use cases for automated flying would be something like going somewhere far away, for example taking a video of a LTE mast and returning to starting point. Moreover, special limitations for flying over the audience have been defined. For example, the multicopter should weight at most 7 kg, the flight height should minimize the possible damage caused to the people and their property and there has to be plans for the use. (Trafi, 2015a)

Finally, the regulation affecting both the recreational and professional users is covered below. The basic rules, like maximum flight height and distance have stayed the same compared to the current legislation. The maximum weight would rise to 25 kg. In addition, it has been stated that flying in the night would not be allowed, except for the civil safety like police and firemen. This makes sense, as it is hard to keep the orientation of the drone in the night. Moreover, the drones are not allowed to be flown nearby specific areas, like airports or power stations. (Trafi, 2015a) A big problem is how to prevent pilots from entering these areas. As a solution a system called geofencing has been suggested. (EASA, 2015) It would require the restricted areas to be preconfigured in the FC which would stop in the border of the area. One problem in this is, that most of the FCs cannot support such functionality. As last, the drone has to avoid all the other aircrafts. Some more obvious points are minimizing noise and property damage to other people, and not disturbing governmental agencies, like police. On the other hand, it has also been stated, that it is possible to make exceptions over these rules. (Trafi, 2015a) The final version of the Trafi (2015b) regulation came out in the end of the year 2015 and it is practically same with the draft.

3 LTE Quality of Service

In this chapter a brief overview over the LTE Quality of Service (QoS) is given. The first section gives a basic introduction. The second section talks about the purpose of QoS. The third section links the Quality of Experience to the QoS. The sections four and five cover the different levels in the QoS. Finally, the last section converses about the utilization and future of QoS based on expert interviews.

3.1 Introduction to LTE Quality of Service

Quality of Service (QoS) has been around almost as long as communication methods have existed. Even with the Morse code, it is important for the QoS to be high enough or the messages cannot be understood. And that is what QoS is all about, having good enough service for the messages to be understandable.

The first time QoS was internationally defined for telephone networks was in 1993 by ITU Telecommunication Standardization Sector (ITU-T). The definition is “The collective effect of service performance which determine the degree of satisfaction of a user of the service”. The same recommendation also notes that “QoS is characterized by combined aspects of” different technical performance factors and is not meant to be used as a sensible measure. (ITU-T, 1993) The 4th Generation Long Term Evolution (4G LTE) QoS will be better explained during this chapter.

Every communication technology has its own way of trying to make the quality of service as good as possible. This also applies to the LTE in which one of the main reasons developing the QoS was reducing the amount of parameters and simplifying the general mechanisms compared to 3rd Generation Universal Mobile Telecommunications System (3G UMTS). Indeed it has been simplified a lot, as can be seen by comparing the UMTS QoS concept and architecture (3GPP, 2014) to the LTE QoS architecture specified in the 3rd Generation Partnership Project Technical Specification (3GPP TS) 23.203 (2015a). For example, the amount of different kind of bearers has been reduced drastically.

3.2 The purpose of Quality of Service

The definition of Quality of Service (QoS) stated above can be understood as a technical measure which describes the service quality. QoS is enforced on many levels from the general network planning to a set of network configuration parameters which define the prioritisation on the communication schema (Mattila, 2015). In the modern telecommunications systems, such as LTE, the most important factor to ensure on the higher level is the service availability (Mattila, 2015). On the lower level they are latency and the bit rate because they have the biggest effect on the QoS (Fitzek, et al., 2002).

Latency, or delay, is the measure of how long does it take for a packet to go forth and back between two machines. The low latency is important in cases which need quick reaction to events such as a conversation or gaming. Latency depends strongly on the network type and distance between the machines.

Bit rate, on the other hand, is the measurement of the transferrable amount of data during a specific time interval and is usually measured as “per second”. Bit rate is important when transferring big files or watching a video from a streaming service, and depends strongly on the usable bandwidth.

Other factors to consider in QoS are jitter and Bit Error Rate (BER). The former means the variation in latency. High jitter makes it hard to estimate the channel, which might be bad for example in gaming. The latter measures the amount of errors compared to the amount of bits transferred and should be as small as possible. (3GPP, 2015a) The examples above illustrate that the tricky part in modern application based telecommunications is meeting the variability in the network requirements of different applications.

On the whole, the purpose of QoS is to optimize these factors, thus making the connection technically as good as possible. This would make every user to have a really good experience. However, a good QoS does not necessarily correlate with the user experience (Kilkki, 2008). The measurement of this user experience is called Quality of Experience (QoE) and is covered, with its relation to QoS, in the Section 3.3 below.

3.3 Relation to Quality of Experience

Kilkki (2008) mentions many different definitions for Quality of Experience (QoE) and defining a proper definition is hard. In this thesis the definition by ITU-T (2007) will be used, because it fits well on the use case. This definition is “The overall acceptability of an application or service, as perceived subjectively by the end-user”. Hence, as the requirements and the expectations for a service can vary between different users, their QoE can differ even in the same instance of a service (Kilkki, 2008).

On the other hand, as explained earlier in the Section 3.2, the requirements can also differ between the use cases. For example, someone having a phone call wants to have low latency and good BER, so the conversation will be fluent and clear. It will be hard to have a proper conversation if the latency goes too high and long pauses are induced between each other’s turns. Furthermore, someone watching a video recording does not care about latency much and is insensitive to errors on the stream. But video needs a high bit rate or the image quality will drop too much. This means that the factors affecting the QoE also depend strongly between the different use cases.

The relation between QoS and QoE has been explained well by Muhammad, et Al. (2006) with “the aim of the network and services should be to achieve the maximum user rating (QoE), while network quality (QoS) is the main building block for reaching that goal effectively”. This means that QoS is a toolset for making the network technically as good as possible and measuring the technical quality, while QoE is the individual opinion on the goodness of the service quality.

As the QoS is measured primarily with the technical factors like latency or bit rate, the QoE is often measured with the Mean Opinion Score (MOS). Good QoS should

correlate with good QoE, especially with the application specific QoS control designed into LTE, but it does not necessarily happen. (Kilikki, 2008)

3.4 First level of LTE QoS – Network Design

An important point in QoS is that it can be applied on many levels. On this thesis they are divided simply into two: network design and QoS configuration. The latter means configuring the LTE QoS specific parameters for different kind of services. It has the biggest impact when the network is approaching congestion, whereas the network design is important in every state of the communication network. In LTE it includes factors like number of cell and core network hardware capability. (Mattila, 2015)

The network design has bigger impact on the service quality in general. It is applied already in the planning phase by ensuring enough resources for the area. Changing the network design afterwards is costly, as it requires adding more hardware to the network. The network design is especially important for the availability of the network. Well-designed network then enables the use of the QoS configuration which does not work if the radio interface is congested. (Mattila, 2015)

3.5 Second level of LTE QoS – Configuration parameters

This part of the thesis concentrates on the LTE QoS configuration. It is performed by setting different kinds of parameters and prioritisations for different kinds of applications. The configuration is about differentiating applications and assuring a specific level QoS for each of them. Furthermore, it is about prioritising specific users, such as civil security, over other users. This is a low level functionality and applies only when the network use is at specific level, often being almost congested. In fact, QoS configuration is practically useless in an empty network as all the resources would be available anyway. And in a congested network the resources are too scarce to divide anymore. Thus it is good to note, that QoS configuration helps only when the radio interface is not congested which might happen in some situations such as big events. (Mattila, 2015)

The precise definition of the LTE specific QoS can be found from the 3GPP TS 23.203 Policy and charging control architecture (2015a). In this chapter the operation of the LTE QoS is explained with the idea and parameters, based on the specification. Thus everything in this chapter is based on this specification, if not otherwise stated.

The LTE QoS is enforced between the User Equipment (UE) and Packet Gateway (PGW), more accurately in the Policy and Charging Enforcement Function (PCEF). Therefore the network parts included in the LTE QoS are UE, eNodeB, Serving Gateway and PGW. Do (2013) has made an explanative figure about the LTE QoS structure and it has been used in the Figure 7 below.

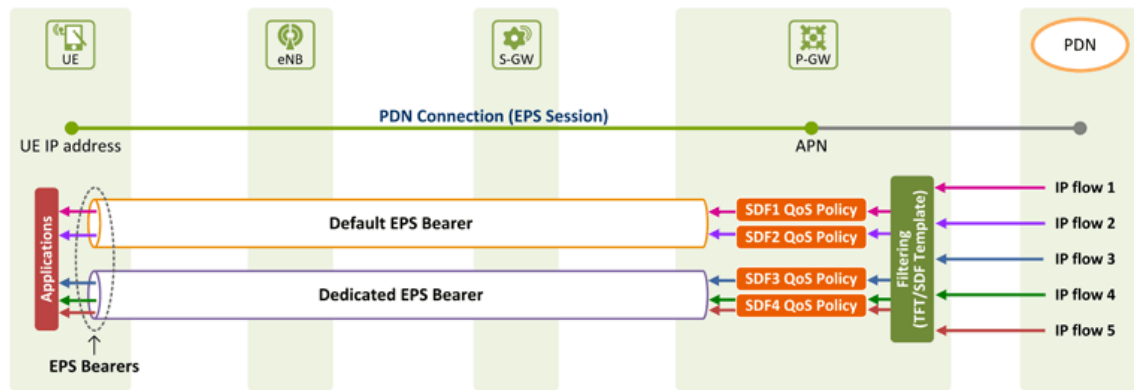


Figure 7. The structure of LTE QoS (Do, 2013)

In LTE each UE connection consists of Evolved Packet System bearers, from now on just bearer, which are like tunnels for similar applications. They can be either of two different bearer types: default and dedicated bearer. The default bearer is initiated when the User Equipment (UE) establishes the connection and there can be only one default bearer per UE. Another restriction is that the default bearer can only have Non-Guaranteed Bit Rate which is explained below. On the other hand, the dedicated bearer does not have such limitations, and is meant to be created whenever a new set of QoS parameters are required. Each application can have its own dedicated bearer. It is possible that all the traffic is directed through the default bearer and dedicated bearer is never created during the lifetime of the connection. The bearers, on the other hand, consist of Service Data Flows which will be explained next. (Ekström, 2009)

Service Data Flows (SDF) are like “pipes” inside the tunnels (bearers). Each application or service has its own SDF with specific QoS parameters, and there can be many SDFs inside one bearer. For example, the normal HyperText Transport Protocol (HTTP) traffic would have one SDF, and a gaming application would have another SDF. The SDF consists of three QoS parameters which are QoS Class Identifier (QCI), Allocation and Retention Priority (ARP) and Guaranteed Bit Rate (GBR).

QoS Class Identifier (QCI) is a combination of the all performance parameters describing how the packet is forwarded. LTE QoS has a set of standardized QCIs meant for different kinds of common applications. The standardized QCIs are listed in the Table 3 below illustrating the default four values for the each parameter and an example application or service it could be used for. As we can see, gaming is delay sensitive, but the Packet Error Loss Rate (PELR) does not matter much. On the other hand, buffered video is latency insensitive, but requires a good PELR. With the priority levels it is good to notice, that smaller value means higher priority. Therefore, in this case the mission critical user plane, including police and firemen, and IMS Signalling, which is used for VoLTE, are prioritised especially high. There can be only one QCI for each SDF. The standardized QCIs are supposed to be used just as guidelines, but by the interviews they are mainly used as is.

The performance related parameters belonging to QCIs are the resource type, priority, maximum packet delay and PELR. From here on these parameters will be explained. Resource type can be either Guaranteed Bit Rate (GBR) or Non-

Guaranteed Bit Rate (Non-GBR) which defines either the minimum bit rate ensured in bits per second (bit/s), or no insurance at all. Priority describes the importance and queuing order for the packages. The lower priority level means higher importance. For example, low priority value packages are prioritized over other packages, meaning that they will be transferred even in a congested network. Maximum packet delay (MPD) defines the maximum delay it should take for a packet to travel from end to end in the network, measured in milliseconds. Thus, the low MPD packets would skip long waiting queues in a congested network. And finally, the Packet Error Loss Rate defines the maximum allowed amount of lost packets.

Allocation and Retention Priority (ARP) consists of three values: “the priority level, the pre-emption capability and the pre-emption vulnerability”. The priority level is a value from 1 to 15, one being the highest priority, which defines how important the resource request is. This is used when deciding if a new bearer is created or rejected when the network is congested or the resources are lacking the requested GBR. Therefore, it is good to notice that the QCI priority comes to effect after a new bearer has been created, compared to ARP which is used before the creation. The pre-emption capability and vulnerability are values of either “yes” or “no”, and they define the pecking order of the SDFs. The capability is used to define if the SDF can take over the resources of a lower priority SDF, and the vulnerability is used for defining if the SDF can be required to give away its resources to a higher priority SDF.

Table 3. Standardized QCI characteristics (3GPP, 2015a)

QCI	Resource Type	Priority Level	Delay Budget	Packet ELR	Example Services
1	GBR	2	100 ms	10^{-2}	Conversational Voice
2		4	150 ms	10^{-3}	Conversational Video (Live streaming)
3		3	50 ms	10^{-3}	Real Time Gaming
4		5	300 ms	10^{-6}	Non-Conversational Video (Buffered Streaming)
65		0.7	75 ms	10^{-2}	Mission Critical user plane Push To Talk voice
66		2	100 ms	10^{-2}	Non-Mission-Critical user plane, Push To Talk voice
5	Non-GBR	1	100 ms	10^{-6}	IMS Signalling
6		6	300 ms	10^{-6}	Video (Buffered Streaming) TCP-based file transport
7		7	100 ms	10^{-3}	Voice, Video (Live Streaming) Interactive Gaming
8		8	300 ms	10^{-6}	Video (Buffered Streaming)
9		9			TCP-based file traffic
69		0.5	60 ms	10^{-6}	Mission Critical delay sensitive signalling
70		5.5	200 ms	10^{-6}	Mission Critical Data (services are the same as QCI 6/8/9)

The QoS can be enforced in two ways. The first is to use only preconfigured QoS Settings for the user subscription. These settings would be defined by the user type for all the applications. The second is to enforce the QoS settings by each application dynamically with the help of the Traffic Flow Templates. They are used for automatic bearer and SDF creation by recognizing new application connections. Such settings should be preconfigured per filter and are automatically activated by the addresses or ports used for the traffic. (Do, 2013)

3.6 Utilization today and visions of the future

From the interviews made for this thesis, it is seen that in Finland the static LTE QoS is used with preconfigured subscriptions. However, using the dynamic QoS does not seem realistic yet, as the QoS structure is complicated. Furthermore, there seems to be lots of difference in the views about how well LTE QoS could be used commercially. The information from the interviews is covered in detail in this section.

There seems to be high variation in the ways and images of how QoS is used nowadays. The most conservative estimate comes from Hämäläinen (2015) who estimates QoS being used only as predefined in the equipment by the network hardware manufacturer. He also notes that VoLTE uses specific QCI classes already, but it isn't used in Finland yet. Pussinen (2015) is on the same lines, as he claims the standard QCI classes are used with just minor tweaks. In his opinion QoS is not productized as classes, such as "gold" and "silver", but is an important part of ensuring good QoE for the customers. A little bit further comes Skarp (2015), agreeing with the previous interviewees, but adds that some service providers, such as the Finnish Broadcasting Company (YLE), is using special QoS services to ensure live news and events. He still agrees that the user amounts for the differentiated QoS are small.

A more optimistic view was given by Mattila (2015) who sees that, even though LTE QoS is used mainly in the basic way for the basic subscriptions, it is also used for ensuring service quality for some services such as the IPTV. Furthermore, QoS is used for some special cases when a user wants to ensure a onetime service. Such service could be a live stream from a concert to an Internet video service.

All the interviewees agree that a need for LTE QoS exists as a way to ensure a high Quality of Experience for the customers. Hämäläinen (2015), for example, said that QoS is an important part of the basic functionality in the network, as it is being used to prioritize the signalling traffic. He also pointed out its importance for Voice over LTE (VoLTE) service, which applies especially for the governmental officer use.

On the other hand, using QoS for differentiating services or subscriptions is rather unnecessary in Finland, where the network quality is high and far from being congested. This ensures that the requested service is always available even without any special QoS differentiation. The situation is different in some other countries, where the LTE coverage is much lower than in Finland. (Hämäläinen, 2015)

Pussinen (2015) also claims that the QoS differentiation is not needed, as the already mentioned class system is already getting more and more unpopular. This means that he does not see a need for example for a gaming subscription with a low latency.

One of the biggest problems in LTE QoS is that it will not help when the radio path is congested, as it does not matter what kind of prioritization and mechanisms the network has if the messages cannot be differentiated from each other on the hardware. (Mattila, 2015) For the governmental officers this is distressing and seems like the only way to overcome this situation would be to move the other users out of the way to a different bandwidth. (Hämäläinen, 2015)

Furthermore, an important factor to consider is the network neutrality which is an ideology that no service should be prioritized over another similar service, like Netflix over YouTube. This can be avoided by selling QoS, for example, evenly for every video service instead says Skarp (2015). Especially giving some specific service a lower QoS would be problematic. An important service which might violate this neutrality is the VoLTE, as it would be prioritized over other services such as the Skype (Hämäläinen, 2015). That can be argued though, Pussinen (2015) states that such problem does not exist, as VoLTE is built-in to the LTE as the default phone service technology and thus is not a service comparable to others.

The biggest problem with the LTE QoS is that it covers only a small part of the end-to-end network. The coverage ends when the packages leave the teleoperator's network. From that point onwards, the quality requested by the packages cannot be ensured. This might happen for example when Netflix has not purchased high enough capacity and cannot serve everyone well enough anymore. It is also hard to know where the problem lies. (Mattila, 2015)

The possible business opportunities and the future of the LTE split opinions. Hämäläinen (2015) and Pussinen (2015) do not see much business for QoS differentiation and think QoS just as a way to ensure the good QoE. Especially Pussinen does not believe in customers being ready to pay for such differentiation. On the other hand, Mattila (2015) and Skarp (2015) have high hopes for LTE QoS.

Mattila (2015) says that QoS makes it possible to get more subscribers and especially the amount of the special use cases, such as live streaming, are growing steadily. On the other hand, he also wonders how to make the money, as multiple players exist when end-to-end QoS is considered. For example, the whole QoS chain for Netflix would be its network operator, the backbone operator and the tele operator. All those parties are affecting the QoS chain, where everyone wants to get more but no one wants to pay, so it would require a long talk between the members. He also believes that in the future the QoS pipe will extend from end-to-end.

The most extreme opinion was by Skarp (2015) with a vision where the future of the teleoperators lies in the QoS. Nowadays the money from QoS can be only taken from the business users, but in the future QoS should be sold more. He goes to such extremes as saying that all the services are built on top of the QoS, and teleoperators would become QoS operators. He also believes on the dynamic QoS

which means applications talking with the network and asking specific kind of service, which the network would then accept or deny. Furthermore, in his opinion a lot of market for QoS exists with replacing the satellite connections at remote places as a good example. The money would come completely from QoS and from many different actors, but in the end it would be the user paying. As a notable point, none of the other interviewees believed on the future with teleoperators becoming QoS operators.

Finally, one of the big questions is how the Internet of Things (IoT) will affect the need for the QoS. The same pattern was seen here as before, Pussinen believing it will not change the situation, as it can be covered with the standard static QoS and Hämäläinen saying it might only effect on the industrial IoT for the beginning. Mattila is a little bit in the middle ground noting, that nowadays most of the IoT works on top of the 2nd Generation Global System for Mobile Communications (2G GSM). And as finally, Skarp thinks that IoT cannot be implemented without smart and dynamic QoS.

To conclude, it is hard to estimate the need of QoS differentiation with the expert opinions varying from pessimistic to optimistic. Obviously, the static QoS is important for the network to work properly, even though it might not be necessary in countries with a high quality network such as Finland. Finally, it looks like there would not be much need for the QoS for the Internet of Things anytime soon.

4 LTE Multicopter Construction

In general commercial cellular connected multicopters do not exist. It has been understandable until now, as the earlier cellular technologies, like Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS), have not had low enough latency and high enough bit rate. Even though the LTE is better in both ways, the consumer LTE multicopters are still non-existent. This is why the LTE connection has to be custom built. However, some Flight Controllers (FC) have been designed to work with other alternative wireless communication methods such as Wireless Local Area Network (WLAN) or Bluetooth. Such capability can be exploited, which makes creating the LTE connection easier. From now on, the way to creating the LTE connected multicopter is explained with the reasons why specific options and parts were chosen.

4.1 Requirements

The selection of multicopters is large. They have different functionalities and the specifications vary. The first problem in LTE multicopter construction is to define the requirements such as size, payload, parts, flight time and additional equipment. Below is the list of the requirements for the multicopter needed in this thesis:

1. A Flight Controller (FC) which has the capability for an alternative wireless control connection, preferably open source. A lot of FCs from expensive completely closed proprietary ones to cheap clones exists, but only few of them have the required capability. Furthermore, a high amount of automated functionalities like flying by the waypoints, geofencing etc. for future use, is required from the FC.
2. Ability to carry 1 – 1.5 kg of laboratory equipment such as metering devices. This would require enough power from the multicopter to be able to lift such weight.
3. Useful flight time should be 30 minutes with the full payload for doing measurements. Finding the balance point between payload and flight time would require good design for the multicopter, which includes the frame, rotor, motor and battery sizes.
4. Stability and easiness of flight for a beginner pilot.
5. A gimbal for attaching a camera for live video stream over LTE.
6. Reliability in motor failure situations as it is meant to carry expensive equipment. As explained earlier in the Section 2.3, different kinds of safety mechanisms for such case between different types of multicopters exist.

To summarize, with these requirements the multicopter should be easy to fly and setup the control link over LTE, it should be capable of lifting up required equipment for the LTE connection with some extra measuring devices, and to continue flying in a case of a motor failure.

4.2 Choosing the multicopter

The requirements reduced the available options heavily. The first requirement, a FC with a capability for a wireless control, is mostly about the electronics and software, and ended up being the biggest problem. The multicopters are generally meant to be piloted over a proprietary radio scheme. Hence the FCs have only a connection for the radio receiver used in these schemes. In the end, only two possible options were found. First one was Mikrokopter by a German multicopter manufacturer HiSystems GmbH (2015). It looked promising in the beginning, as their software is open source and there was information about using these multicopters over WLAN and Bluetooth connections. However, the functionality for the alternative connection types has been removed in the newer versions of the product. It would have been possible reimplement the alternative connection again as the software is open source. However, it seemed too complicated to perform in the scope of this thesis.

The second option, which seems to be the only option supporting alternative connection schemes, is any FC using Ardupilot software. It supports receiving control messages over a two way telemetry port. Telemetry, by Merriam-Webster (2015b), means “the process of using special equipment to take measurements of something (such as pressure, speed, or temperature) and send them by radio to another place”. Thus, Ardupilot software supports controlling over a port which has originally been meant for sending information from the multicopter to the GCS. A FC having such a two way telemetry port seems to be rare, but one of the FCs supporting this is the Pixhawk by the 3D Robotics (2015), which seems to be also otherwise capable and fitting for the requirements.

The rest of the requirements are related to the mechanical parts, like the frame, propellers and motors. The second requirement, the ability to lift more than its own weight and a small camera, removed all the toy multicopters from the list. Moreover, the sixth requirement for the motor failure recovery made quadcopters useless, as they cannot recover from such situation, as explained in the Section 2.3. On the other hand, the fourth requirement of being easy to fly and stabile removed the octocopters as they tend to be sensitive to wind and are too big for beginner pilots.

Finally, the biggest challenge not related to this thesis, was buying or building a multicopter which would fulfil the third requirements. No multicopter fulfilling the requirements is sold in Finland. Buying it from Finland was important for better support afterwards. This means that the multicopter had to be custom built either by the thesis team or ordered from somewhere else. In the end, building a custom multicopter was left to the knowledgeable hands of the members of EuroRC, a Finnish radio controlled devices hobby shop (2015). As a final outcome a Hexacopter fulfilling the requirements was built.

4.3 LTE Connection

After choosing the multicopter, it is time to create the LTE connection from the PC used for controlling to the Flight Controller (FC) of the multicopter. On a PC it is

simple to create an LTE connection to the Internet. A plethora of LTE Universal Serial Bus (USB) dongles are available and usually they support plug and play. But the big question is, how to connect the FC to the LTE. The construction of the LTE connection explained here is strongly based on the work of Egeland (2015) and his tutorial which has also been modified later on by the results of this thesis. This section explains the necessary steps for creating the connection. More detailed instructions can be found in the Chapter Appendix C - - LTE Setup

The Pixhawk FC does not have the capability of attaching and using any kind of LTE device straight out of the box. However, it does have a two way serial telemetry port which has been designed to be used with any wireless communication scheme. The question is how this port can be connected to the LTE network.

In this thesis, a Raspberry Pi (RPi), shown in the Figure 8 below and running Raspbian Linux distribution, was chosen as a router between the LTE and the FC. It is a fitting device for this purpose, because it is easy to use, lightweight which is an important factor on drones, flexible for other possible needs, and can also be used for streaming the video. It is powered by a micro USB port, so it is possible to use a 5 volt Battery Eliminator Circuit (BEC) with a micro USB adapter to power the RPi.



Figure 8. Raspberry Pi B+ used as router. (Everard, 2014)

It was assumed that any LTE USB dongle could be used straight out of the box with RPi. However, this was not true with the dongle chosen to be used. The first problem with the RPi with LTE dongles is that it does not provide enough current to the USB-ports. Hence, some kind of way to overcome this disadvantage is needed. On a desktop Personal Computer (PC) the LTE dongle would be attached on a powered USB hub, but is not possible to have such hub on the multicopter. Another way is bypassing the RPi power supply protection, which also requires bypassing the USB power connector. This can be done by soldering a female USB cable on the RPi circuit.

Now, as the RPi and LTE dongle are powered, it is time to make the Raspbian Operating System (OS) to use the dongle. Raspbian has a large selection of supported dongles and also the chosen dongle should work out of the box. Once again, this is not true and the dongle needs to be set up to be recognized correctly as a LTE device. Furthermore, Raspbian uses LTE devices with the Point-to-Point Protocol (PPP) interface by default. This does not provide the full capacity of LTE as it should be used as a Wireless Wide Area Network (WWAN) device. However, a program called uqmi can be compiled and used for this purpose.

Next step is to make RPi connectable and controllable easily, as it cannot have monitor and keyboard on-board the multicopter. First thing required is an SSH connection and the default OpenSSH-server is recommended. Next it has to be made possible to connect the RPi after the boot, without knowing its IP address. Obviously, this means using a Dynamic Domain Name System (DDNS) service. For this thesis a free DDNS called freeDNS was used because it is easy to set up. The IP address can be updated by downloading a web page which makes it possible to use any browser or wget which is a Linux terminal webpage download tool. After writing Python script to use wget to download the specific web page, the RPi is reachable easily after the start-up.

The Figure 9 below illustrates the connections of the copter. The complexity of the connections can be seen well. The power connections are shown in red and wired connections are blue. For the wireless connections the traditional RF connection is marked with dashed green and LTE connection with dashed orange.

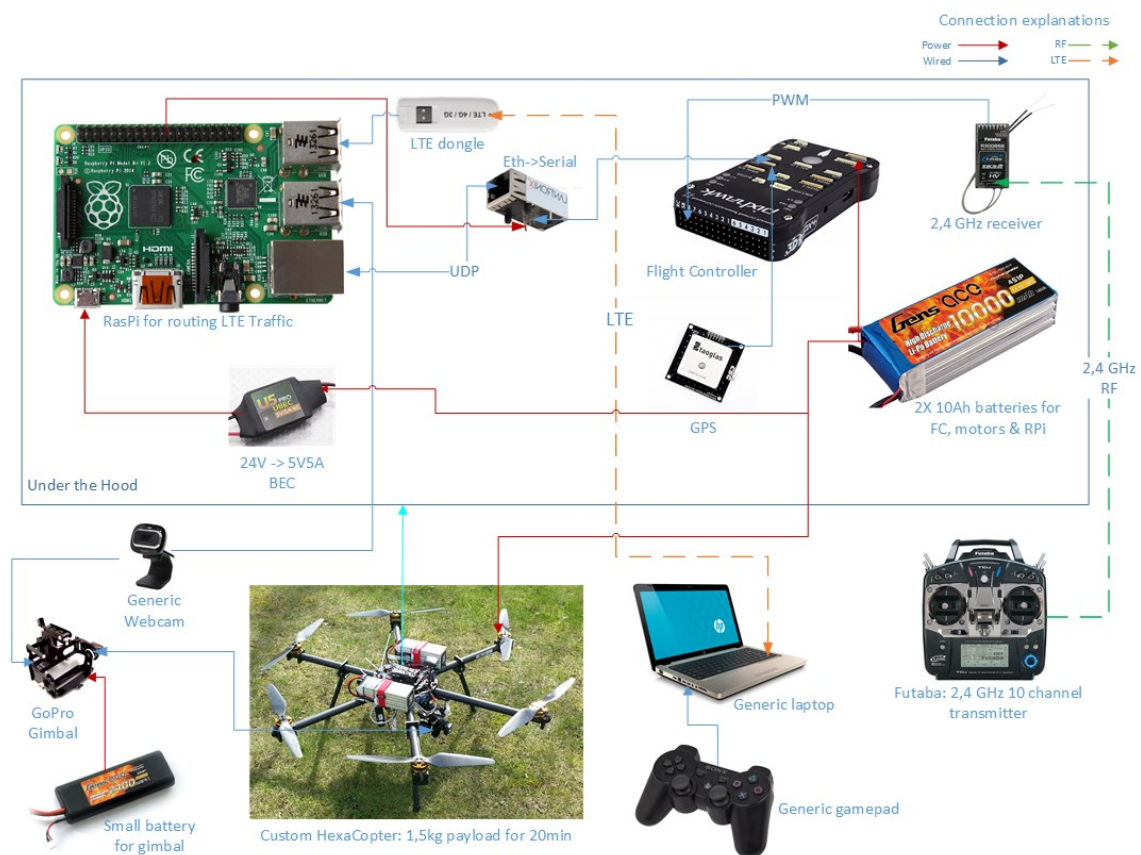


Figure 9. LTE Multicopter connection scheme

4.3.1 Routing the Control Messages

Next and the final step to make the routing, and thus piloting over LTE work, is connecting the RPi to the FC. RPi would have a Generic Purpose Input/Output (GPIO) interface which could be used to communicate straight with the telemetry port on the FC. However, enabling the User Datagram Protocol (UDP), instead of Transmission Control Protocol (TCP), with the GPIO interface is complicated. It is necessary to use UDP, as is the preferred protocol for this kind of control message traffic, as the latency needs to be as low as possible and it is not necessary to make sure every packet gets through, like with game traffic. This is why a transistor-transistor logic (TTL) serial to Ethernet adapter, shown below in the Figure 10, is needed. Hence, the RPi needs to be connected to the adapter with an Ethernet cable, and then the adapter needs to be connected to the telemetry port. For this the original Pixhawk telemetry cable needs to be split and soldered on the pins of the adapter. After the cables are connected, UDP routing software needs to be started on the RPi. A lot of options exist for this purpose and in this thesis a script called UDP_redirect is used with a Python script on start-up. Now the routing works from the LTE connection to the FC.



Figure 10. TTL to Ethernet adapter by Lantronix (GM Electronics, 2015)

4.3.2 Sending Video

The next phase is to set up a video link from the drone to the PC. For this purpose a camera with streaming capabilities is needed. Surprisingly it was found out that the GoPro Action camera supports only video recording so it cannot be used for this purpose. Instead any kind of USB web camera fits for this purpose. It is better to choose a camera which works with the RPi low power USB ports, even though it is possible to use an external power source, like explained in the Section 4.3. Generic web cameras are also easy to use, as they are nowadays recognised and ready to use out-of-the-box on Raspbian. Now the video taken by the camera needs to be sent for the GCS PC. This kind of live video is called streaming. In this case a streaming software called GStreamer was chosen and configured for both ends, the RPi and PC. The video quality settings were chosen so that the required bit rate was close to 10 Mbit/s.

4.4 Setting up PC

Any kind of PC with Microsoft Windows can be used as a Ground Control Station (GCS). In this thesis a generic laptop running Windows operating system was used to achieve good mobility. The most important tool on the PC side is installing the GCS software explained in the Section 4.5 below. The GCS software supports any kind of Internet connection such as WLAN or even Ethernet. For now the LTE was again chosen to achieve the required mobility for this thesis. Furthermore, any kind of control scheme can be used, but at least an analogue control method should be chosen for more accurate control. For this thesis a generic gamepad, shown below in the Figure 11, was chosen as the control device. In addition the GStreamer was also installed on the PC to receive and show the video to the user.



Figure 11. A Logitech Dual Action gamepad (Logitech, 2015)

4.5 Ground Control Station Software

The other half of the Flight Controller (FC) is the Ground Control Station (GCS) Software. It is a program delivered by the FC manufacturer, which means that most of the manufacturers have their own version of a GCS. Nowadays it is mainly used for setting the drone up. The user can use a wizard for the first time setup, where all the different sensors are calibrated, adjust parameters and activate functionality, like Return to Home. The second most important purpose is showing the telemetry data from the drone. This data includes information like current battery charge level and location on a map. Lastly, amongst all the lesser functions, it has a black box style logging from the flight with all the information saved on the PC. In addition, some of the GCS software, like the one used with the Pixhawk FC, support controlling the drone with a PC peripherals, such as gamepads or joysticks. Figure 12 below illustrates a GCS.



Figure 12. An example of the Ground Control Software

5 Use Case: 3D LTE Coverage Measurement

In this chapter an Long Term Evolution (LTE) controlled multicopter use case for a 3D LTE coverage measurement is performed. The first section gives a brief explanation on the 3D LTE coverage measurements. The second section introduces different types of measurements. The third section converses about the possible problems in performing such measurements. And finally, in the fourth section, two different measurement cases are performed and their usefulness analysed.

5.1 Introduction to 3D LTE coverage measurement

Measuring the cellular network signal quality is an important tool in the network design. Until now the measurements have been made mostly on the near ground level, because that is where most of the mobile phone use happens. But undeniably the information of the network coverage at the higher altitudes is also an interesting topic. Such coverage measurement executed both horizontally and vertically, is called 3D measurement. It can be used in designing the network at a future sky scraper location by measuring the interference from other networks, or the current network coverage. Moreover, the whole network might need to be designed to cover also higher altitudes, as the drones are starting to rely more on the LTE connection on-board, like introduced in the end of the Section 2.4 Multicopter users and applications. The interference measurement can also be performed without existing cells or having the network in an off state. Furthermore, a 3D measurement can be used for improving the connectivity at a stadium or to learn about the LTE network behaviour in general, to mention a few use cases. The methods used nowadays, such as weather balloons, are cumbersome to use and hard to control. On the other hand, a multicopter is both easy to use and control, which makes it a versatile platform for the 3D measurements.

In this chapter an example use case for a 3D LTE measurement is executed. The purpose is to test the feasibility of the LTE multicopter setup for such use, and to develop the methodology required for a 3D measurement. This includes testing out different kinds of important methods and measurement situations such as vertical, on border of an obstacle and zigzag. Furthermore, the data collected and the methods are evaluated by the usefulness.

The setup used is the LTE multicopter built for this thesis which carries a Samsung Galaxy S5 mobile phone with Nemo Handy application installed. The Nemo Handy records all the necessary information from the network, such as Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), altitude and neighbouring cells. The measurements were made in the Otaniemi NetLeap network.

5.2 Different types of measurement cases

The coverage measurements can be performed in many ways. For example, one of the interesting cases is the LTE coverage compared to the altitude, which would be a “one direction” measurement. One such measurement case would be the “horizontal” measurement which is performed by moving the meter at a specific altitude plane. This case matches the traditional walk or drive by measurement.

Another “one direction” case is the “vertical” measurement where the meter is moved straight upwards. Usually such vertical measurement is also called as 3D measurement, even though it is actually one dimensional. Such measurements are already performed with a meter attached onto a weather balloon which then carries the meter up. Both cases above can also be used for the “on the border of an obstacle” measurements which could be used for measuring the attenuation of an obstacle. The attenuation can be seen from the change in the signal strength when the drone moves from behind the obstacle to have a line of sight to the eNodeB.

The measurement cases mentioned above are important, but they are not true 3D measurement cases. Furthermore, they do not bring out the full possibilities of an LTE multicopter which can be used to combine the different measurement methods to a true 3D measurement case. This method will be called as “zigzag” case from its nature of going back and forth either horizontally or vertically to cover a big area. The multicopter is easy to fly in any desired path and it can be flown both manually or automatically, which makes it a versatile tool for covering big areas at different locations and altitudes.

5.3 Possible problems

Even though the multicopter is a formidable platform for 3D measurements, it does not mean there would not be any problems. For example, the maximum flight time and maximum wind need to be considered in the planning phase. The battery capacity and used payload affect a lot on the maximum flight time. Even though the current battery levels can be seen from the GCS software, it is important to plan the measurement well. Furthermore, the exact location of the measurement effects on the wind. For example, the middle of the forest has less wind than on an open area. A surprising point to notice is that a narrow path between buildings can have strong crosswinds which can make flying a multicopter challenging. Furthermore, the wind is stronger at the altitudes of 100 meters than near the ground, which consumes much more battery as balancing the multicopter needs to be more frequent.

Some of the problems in multicopter 3D measurements are equipment related. For example, how to protect the equipment from possible crash on the ground or water, what if it starts raining, what to do if the multicopter malfunctions, and should the measurement equipment pull the power from their own batteries or from the multicopter batteries. It is important to make sure all the batteries are charged before starting the measurement. Furthermore, it should be noted that a low LTE signal strength can make it impossible to pilot the multicopter over the LTE connection. Thus LTE multicopter is not good for measuring the low signal

strength locations, but this problem can be avoided by either using the traditional RC controller or automated flying.

Finally, some of the major problems are related the measurement results and come from the interference. Indeed, the airspace is filled with signals from different sources and their effect has to be considered. One such source is the different radio sources such as other cellular networks and radio controllable drones. In some situations another operator's antennae might be right next to the measurement location while the cell being measured is further away. Such situation might create strong interference to the measurements. Another source is the electronics on-board the multicopter such as the GPS receiver, RC receiver and static noise from the power board, ESCs and motors. Thus, one important point for the 3D measurements is measuring the noise created by the multicopter equipment.

5.4 Test cases

Some important steps need to be executed to make a good 3D measurement. First, the location has to be chosen. The reason can be for finding good antenna angles or positions for new cells on an old location, or designing the network on a new location or for new buildings, or getting better knowledge of the network behaviour in general. Second, the type of the measurement has to be decided. Will it be a pure vertical measurement or zigzagging over a larger area and should the multicopter be piloted manually, automatically or mixed? Third, the equipment has to be chosen such as should the antenna be omnidirectional or accurately directed. Latter would be especially important on a new building planning, as the building has high attenuation and the network coverage can vary on different sides of the building.

Two tests were made for this use case with two different kinds of straight vertical tests. Zigzag tests were not made because of software issues, and pure horizontal tests were not made as they have less novelty value than vertical measurements. The locations were chosen based on the earlier horizontal measurements performed with a car. They offered a good image of the signal quality on the ground level. The base station locations, the earlier car measurement results and the new 3D measurement locations, marked with red circles, can be seen in the Figure 13 below. The test 1 was chosen to be performed in a location with an average RSRP of -90~-100 dBm on the ground. Test 2 was started from the ground behind a building and then raising over the rooftop level.

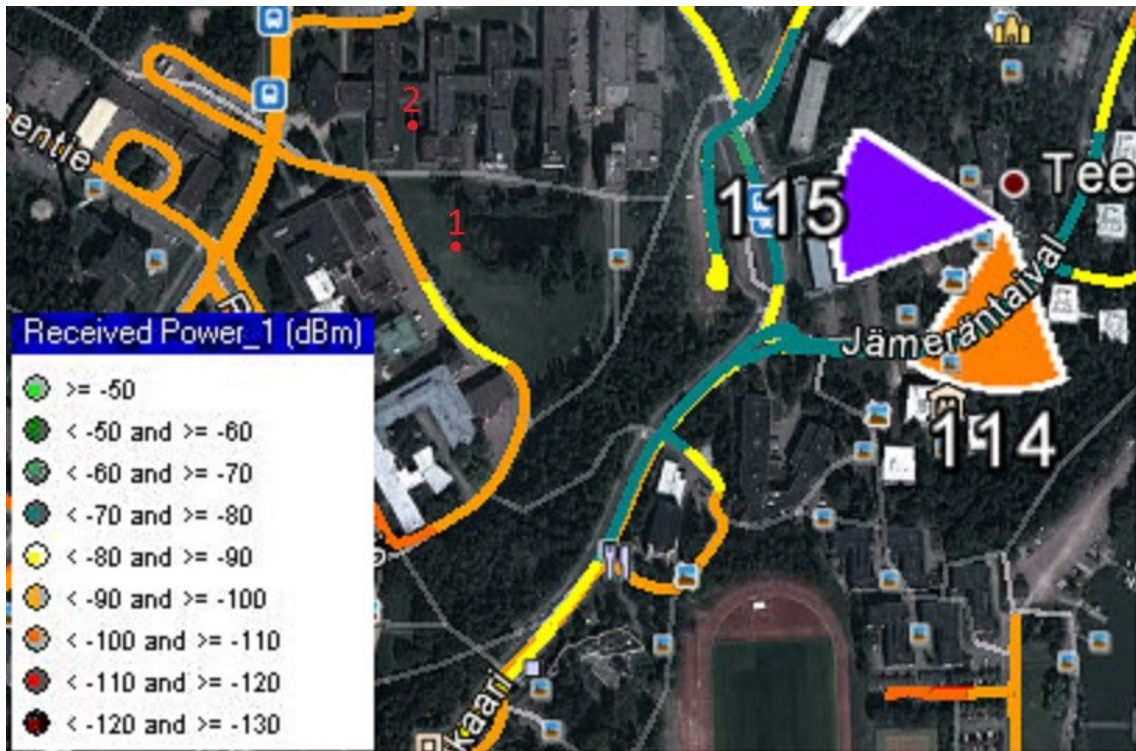


Figure 13. Old measurement and 3D measurement locations

The values measured are the RSRP and RSRQ as they give a good estimate of the signal quality. The Reference Signal Received Power (RSRP) is the power of the useful signal, compared to the Received Signal Strength Indicator (RSSI) which measures all the power, unit Watts, in the relevant bandwidth including all the neighbouring cell interference and other noise. The Reference Signal Received Quality (RSRQ) is the measure of the quality of the received signal and is calculated from the RSRP and RSSI with the Equation 1 below where N is the amount of Resource Blocks (RB) used in the measurement. (ETSI, 2015b)

$$RSRQ = \frac{N * RSRP}{RSSI} = \frac{[dBm]}{[dBm]} = [dB] \quad (1)$$

The tests are explained in more detail and results are shown in the following sections. Both tests results were as expected. More accurate tables of results can be found in the Appendix A - Measurement results.

5.4.1 Test 1: Vertical test with average signal quality

In the first test the multicopter was flown vertically straight upwards to see how the altitude affects to the signal quality. To illustrate the measurement location, the Figure 14 below shows the ground surface shape and the obstacles between the multicopter and the eNodeB. In this case, the starting location and LTE eNodeB have a big difference in height. Furthermore, an apartment building and some forest are in between the starting location and the eNodeB. Thus a significant

improvement in the signal quality is expected with the addition in altitude. The maximum altitude gathered in this test was 74 meters.



Figure 14. Test 1 pattern, surface shape and obstacles

The RSRP measurement results for this test are shown, in dBm in relation to the altitude in meters, on the Figure 15 below. It includes minimum, average and maximum values of the measured RSRP. The final measured values are close to what was expected. In the beginning the RSRP grows a bit faster, but at 34 meters the value starts to drop fast. Still, the RSRP stays around average of -87 dBm which is higher than the average of -93 dBm in the beginning. This kind of result can be explained with the cell antenna being directed downwards to barely cover the building in front of it, especially as the antenna is located on a high spot. The 34 meters can be estimated to be around the rooftop level of the building in between when compared to the starting altitude. The variance between the maximum and minimum values is relatively small.

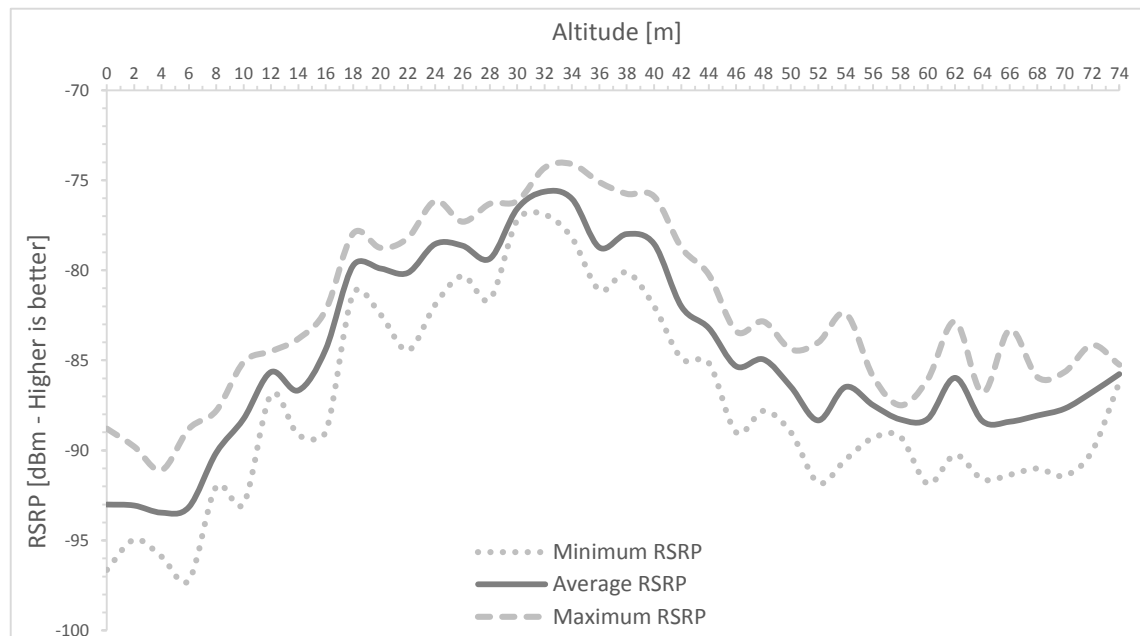


Figure 15. RSRP results from the test 1

Next, the RSRQ measurement results for this test are shown, in dB in relation to the altitude in meters, on the Figure 16 below. It includes minimum, average and

maximum values of the measured RSRQ. Again, the final values obey to what was expected. First, it does not seem to follow the RSRP at all. Second, the RSRQ is declining all the time. This could be explained with the amount of interference and noise increasing all the time more than the RSRP. This relation can be seen from the Equation 1 in the Section 5.4 above. This kind of outcome is likely as there is less obstacles and attenuation at the higher altitudes so there is more cells interfering. The variance between the maximum and minimum values is relatively high.

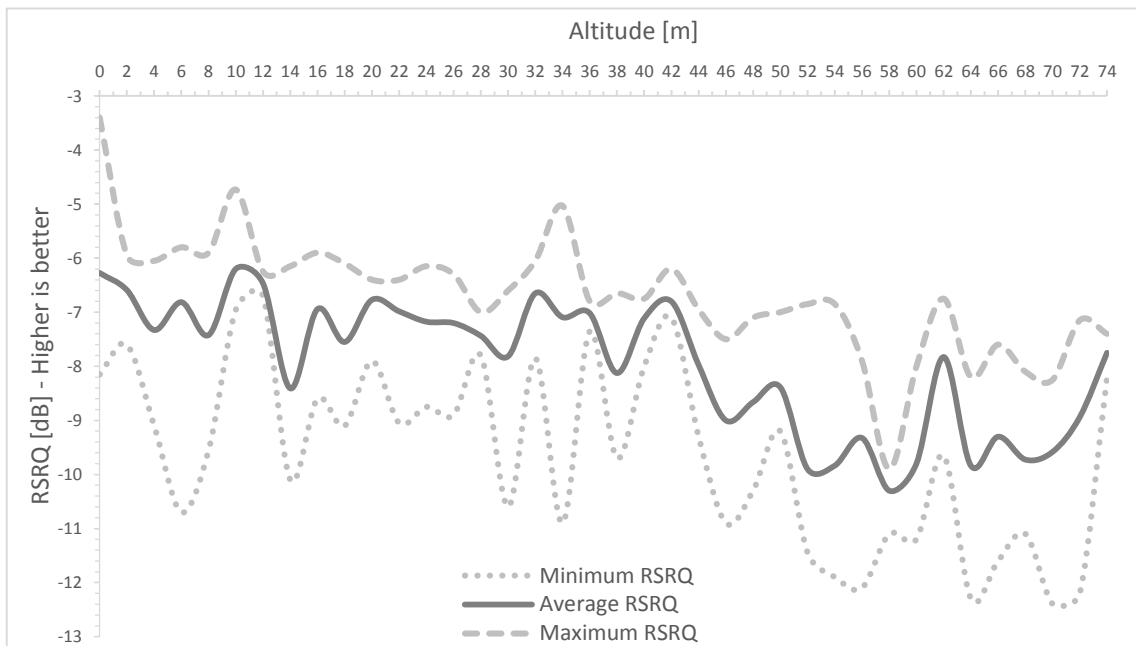


Figure 16. RSRQ results from the test 1

5.4.2 Test 2: Vertical test from behind a building

In the second test the multicopter was started from behind a building to see how the building affects to the signal quality. No previous measurement data exists from this location, but from the Figure 13 in the Section 5.4 can be seen that the expected starting RSRP should be less than -90~-100 dBm, as the building will attenuate the signal. To illustrate the situation at the measurement location, the Figure 17 below shows the ground surface shape and the obstacles between the multicopter and the eNodeB. The main difference compared to the test 1 is that the starting location is next to a building. Thus a significant improvement in the signal quality is expected when the multicopter rises above the building attenuating the signal. This measurement can be especially used to see the attenuation from a building. The maximum altitude gathered in this test was a little above the building roof level ending up with the altitude of 24 meters.

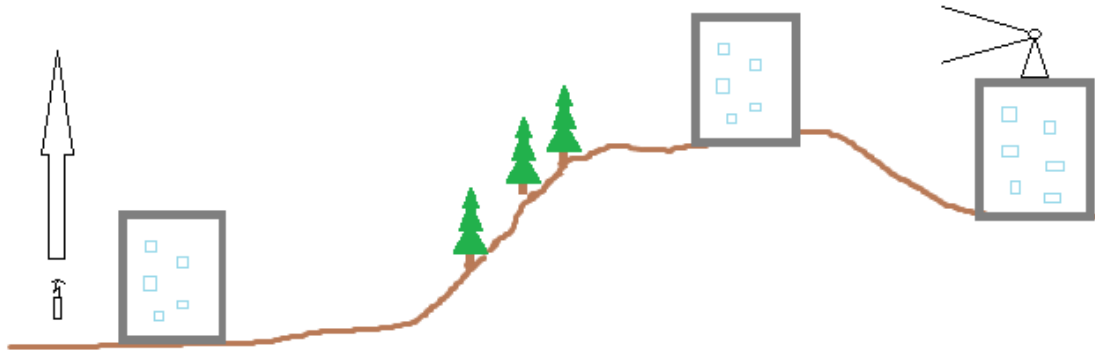


Figure 17. Test 2 pattern, location surface shape and obstacles

The RSRP measurement results for this test are shown, in dBm in relation to the altitude in meters, on the Figure 18 below. It includes minimum, average and maximum values of the measured RSRP. First, the RSRP is increasing at the same base speed for the whole measurement with small notches deviating from the trend. Thus it basically seems like there is no building attenuating the signal at all. Second, interesting points are the notches marked with diamonds on the average RSRP line and more visible on the maximum RSRP line. Considering that the altitudes for the notches are every 2.4 meters, it can be said that they are the effect of the signal travelling through windows. So it seems that windows have strong effect on the RSRP even at such location far from the cell antenna and other obstacles in the way. The rooftop level is likely to be at the final notch at the 14.4 meters or at 17.6 meters where the minimum and maximum lines converge to the average line. In general it can be seen that the attenuation from the building is around 17.5 dB. The variance is small except around the windows where the maximum values diverge heavily from the minimum values.

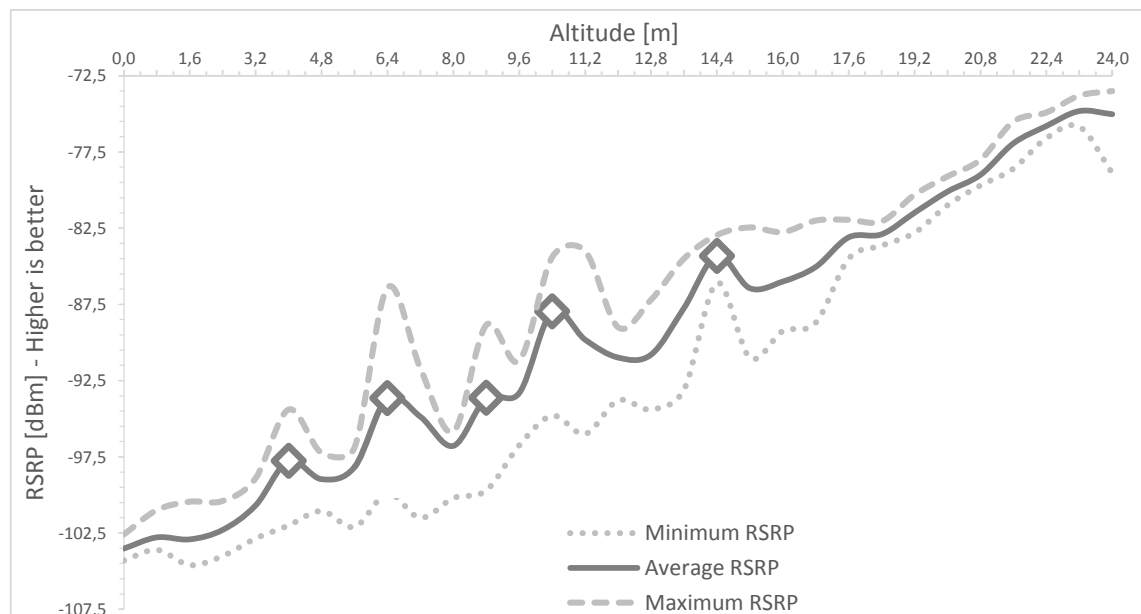


Figure 18. RSRP results from the test 2

Next, the RSRQ measurement results for this test are shown, in dB in relation to the altitude in meters, on the Figure 19 below. It includes minimum, average and

maximum values of the measured RSRQ. The RSRQ values seem to differ from the RSRP pattern as could be expected after the first test case. At first it is hard to see any kind of trend and the variance is tremendous. However, there is a weak rising trend towards the better, which can be seen from the maximum RSRQ line. Furthermore, it seems that especially the minimum RSRQ value tends to drop around the windows. As whole, there is lots of fluctuation in the minimal RSRQ value and it tends to affect the average value heavily. Furthermore, the variance is high between the minimum and maximum values of the RSRQ.

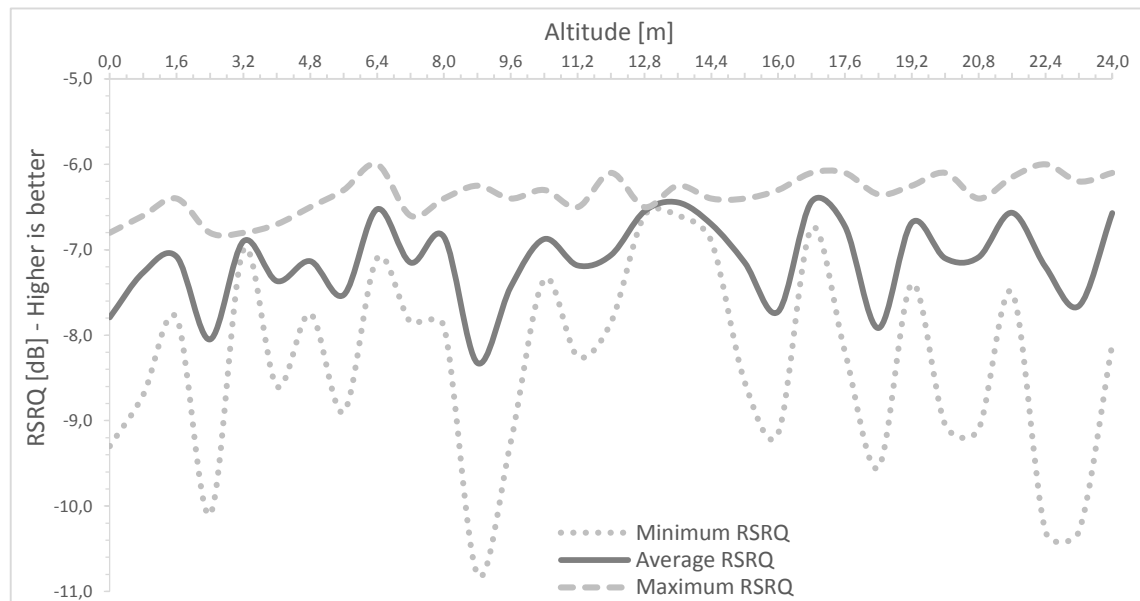


Figure 19. RSRQ results from the test 2

5.4.3 Assessment of the test case results

The test cases were both successful and revealed unexpected results on how the LTE network behaves in vertical direction. Both the RSRP and the RSRQ values were different than expected. In addition, their relation is surprisingly weak. The handovers were not made during these test cases and thus they were not included in the results. In any case, these tests prove that the 3D measurements could be a useful tool for the network design.

Furthermore, the multicopter is easy to use and works as expected in this kind of use case. With the modern functionalities it can fly straight up with constant speed even in the semi-automatic piloting mode and it is stable even until the 74 meters high. Moreover, live data about the multicopter status, such as batteries and altitude, can be seen with an LTE, or similar, connection. This makes it easy to avoid mistakes and problems during a measurement.

For future measurements, a live data about the current LTE RSRP should be added. Also further measurements should be made in different cases such as zigzag, background interference and handovers at high altitudes. Also the equipment should be changed to more fitting ones and use for example directed antennas.

6 Conclusion

In this thesis many areas were covered from the history of the multicopters and LTE QoS to their future. Furthermore, a multicopter controllable over a LTE connection was built and its feasibility analysed. Next, a 3D LTE coverage measurement was performed and measurements collected and evaluated as an example use case. In this conclusion the results are shown and assessed, and possible problems and the future of LTE connected drones analysed. Finally, the required future research is covered.

6.1 Results

The main result of this thesis is proving the achievability of a multicopter controllable over an LTE connection. As a proof, such multicopter was constructed and is verified to be working. The LTE connection responsiveness is then evaluated against the traditional Radio Controller (RC) and is found to be feasible. Moreover, the other benefits, such as the coverage, of the LTE connection over the RC are shown to be true. The LTE is also verified to have a high enough bit rate to have live video stream from the multicopter, which facilitates Beyond Visual Line of Sight flying.

The LTE multicopter is then tested as a 3D measurement platform. This is made by performing two different vertical measurements. The multicopter is found to be stable, easy to use, to have a good payload and it can be made to fly over specific route automatically. Furthermore, it is possible to receive live status information from the multicopter and LTE connection to the ground control station.

Moreover, interviews were made to include expert opinion over the current level of use and feasibility of the LTE QoS. The mobile operators are using it on different levels. Some are using only the default configuration and some are offering customised QoS services. As whole the LTE QoS is found to be working as designed. However, there are some situations where the usefulness diminishes such as the eNodeB being completely congested.

6.2 Assessment of Results

The main topic in this thesis was a hand-on construction project. Furthermore, the thesis stayed on a high level all through the thesis. Hence, no exact measurements and results were gathered. Still the information gathered is valuable as a proof of concept and made it possible to use a new way to pilot drones. Moreover, the resulting LTE drone is a fact which cannot be denied. On the other hand, more time could have been used for developing the LTE connection further, for example, by making the connection to work over a public network. However, this thesis was supposed to be performed in the private network so such functionality was not necessary.

The 3D measurement test case proved the feasibility of a multicopter as a platform, but the results were vague because of performing them only one time. However,

the research done in this thesis can be used as a base for more accurate and complex measurements. The importance of such measurements is going to grow when the LTE drones become more common as they are highly dependent on the LTE network. Next, the use of multicopters for 3D measurements has to be advocated to make them a common tool in the field.

LTE Drones do also have some problems. For example, it is obvious, that a LTE devices flying at 150 meters would cause some problems in the network, like is known to happen with the skyscrapers. The possibility for flying Beyond Visual Line of Sight (BVLOS) also raises all kind of questions about the safety and problems. For example, it safe to fly even with the FPV equipment, as the visibility to surrounding areas is really poor. It is also hard to control the distances and hard to know when the LTE coverage ends. This might make the drone to drop on top of a high traffic road causing accidents.

The interviews gave good information on the LTE QoS, but it is hard to do conclusions from the data. The interviewees had really strong differences in their opinions and a consensus cannot be found. However, the results indicate the many possibilities of the LTE QoS and that there is space for growth.

6.3 Exploitation of Results

The LTE benefits are obvious for a multicopter a control connection. It extends the maximum flight distance and especially makes it possible to fly without visual line of sight from the pilot to the multicopter. This is important when flying behind a building or another big object which will attenuate the traditional radio control link. The LTE multicopters can be used in many ways, including long distance check-ups and following criminals for long distances. Now it is time for the commercial companies to realize the possibilities and start manufacturing and using them. To summarize, the LTE is a good option for the traditional radio control.

An LTE multicopter is a viable platform for 3D measurements. It can be used without problems and can carry even heavier equipment. Now it would be a good time for the mobile operators to start using multicopters for network coverage measurements. 3D measurements become even more important when LTE drones start to become more frequent as they are devices flying at high altitudes. This requires a completely new ways in designing the network. Without a doubt, the 3D measurements are a beneficial tool for network design.

The LTE QoS has been proven to work well and it is possible to prioritize specific services. The next thing would be defining a new QoS Class Identifier (QCI) class for the LTE multicopters which are sensitive to latency. This would help against problematic situations such as connection loss in a congested network.

6.4 Future research

From the amount of news and research on drones we can see the amount of interest on them. The hobbyist flying and professional video recording businesses

have been growing steadily and now some companies are on the verge of starting package deliveries. Multicopters are planned to be used for emergency situations, like ambulance missions and police crowd control. For now it seems like endless possibilities exist.

Now adding LTE on drones would break the last big constraint for most of the use cases covered in this thesis, the limited range of the traditional radio. With LTE making it possible to control the drone without distance limits, there could be drone depots with drones launched from hundreds of kilometres away, flying tens of kilometres until the batteries run out. This would save lots of money, not having to send the personnel on the location, and lots of time, as the help could be sent fast in a beeline.

As future research still some work to needs to be done, as this thesis was mainly for building the LTE connection for a drone. It would be good to make redundancy for the LTE control, as one operator networks can be lacking in coverage, and it would grow reliability. Next, the LTE coverage behaviour should be measured until 70 meters high. Furthermore, more intelligence should be added to handle situations such as complete signal loss and obstacle on the flight path. Finally, the application level LTE QoS effects should be measured on real network.

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Appendix A - Measurement results

1 Test 1 RSRP results

Altitude [m]	Minimum RSRP [dBm]	Average RSRP [dBm]	Maximum RSRP [dBm]
0	-97	-93	-89
2	-95	-93	-90
4	-96	-93	-91
6	-97	-93	-89
8	-92	-90	-88
10	-93	-88	-85
12	-87	-86	-85
14	-89	-87	-84
16	-89	-84	-82
18	-81	-80	-78
20	-82	-80	-79
22	-84	-80	-78
24	-82	-79	-76
26	-80	-79	-77
28	-82	-79	-76
30	-77	-77	-76
32	-77	-76	-74
34	-78	-76	-74
36	-81	-79	-75
38	-80	-78	-76
40	-82	-79	-76
42	-85	-82	-79
44	-85	-83	-80
46	-89	-85	-83
48	-88	-85	-83
50	-89	-86	-84
52	-92	-88	-84
54	-91	-86	-82
56	-89	-87	-86
58	-89	-88	-88
60	-92	-88	-86
62	-90	-86	-83
64	-92	-88	-87
66	-91	-88	-83
68	-91	-88	-86
70	-91	-88	-86
72	-90	-87	-84
74	-86	-86	-85

2 Test 2 RSRQ results

Altitude [m]	Minimum RSRQ [dB]	Average RSRQ [dB]	Maximum RSRQ [dB]
0	-8	-6,3	-3
2	-8	-6,6	-6
4	-9	-7,3	-6
6	-11	-6,8	-6
8	-10	-7,4	-6
10	-7	-6,2	-5
12	-7	-6,5	-6
14	-10	-8,4	-6
16	-9	-6,9	-6
18	-9	-7,6	-6
20	-8	-6,8	-6
22	-9	-7,0	-6
24	-9	-7,2	-6
26	-9	-7,2	-6
28	-8	-7,4	-7
30	-11	-7,8	-7
32	-8	-6,7	-6
34	-11	-7,1	-5
36	-7	-7,0	-7
38	-10	-8,1	-7
40	-8	-7,1	-7
42	-7	-6,8	-6
44	-9	-8,0	-7
46	-11	-9,0	-8
48	-10	-8,7	-7
50	-9	-8,4	-7
52	-11	-9,9	-7
54	-12	-9,8	-7
56	-12	-9,3	-8
58	-11	-10,3	-10
60	-11	-9,8	-8
62	-10	-7,8	-7
64	-12	-9,8	-8
66	-12	-9,3	-8
68	-11	-9,7	-8
70	-12	-9,6	-8
72	-12	-8,9	-7
74	-8	-7,8	-7

3 Test 2 RSRP results

Altitude [m]	Minimum RSRP [dBm]	Average RSRP [dBm]	Maximum RSRP [dBm]
0,0	-104,3	-103,5	-102,6
0,8	-103,6	-102,8	-101,0
1,6	-104,6	-102,9	-100,5
2,4	-104,0	-102,3	-100,4
3,2	-102,9	-100,7	-98,9
4,0	-102,0	-97,8	-94,4
4,8	-101,1	-99,0	-97,3
5,6	-102,1	-98,2	-96,9
6,4	-99,9	-93,6	-86,4
7,2	-101,5	-94,9	-91,7
8,0	-100,2	-96,8	-95,9
8,8	-99,7	-93,6	-88,9
9,6	-96,8	-93,3	-91,2
10,4	-94,8	-88,0	-84,4
11,2	-96,0	-89,8	-84,0
12,0	-93,8	-91,0	-89,0
12,8	-94,4	-90,8	-87,2
13,6	-93,1	-87,7	-84,5
14,4	-86,1	-84,3	-83,0
15,2	-91,0	-86,4	-82,5
16,0	-89,3	-86,0	-82,8
16,8	-88,7	-85,0	-82,0
17,6	-84,5	-83,1	-82,0
18,4	-83,7	-82,9	-82,1
19,2	-82,8	-81,5	-80,3
20,0	-81,0	-80,1	-79,1
20,8	-79,7	-79,0	-78,0
21,6	-78,6	-76,9	-75,5
22,4	-76,6	-75,8	-74,9
23,2	-75,9	-74,8	-73,8
24,0	-78,9	-75,0	-73,5

4 Test 2 RSRQ Results

Altitude [m]	Minimum RSRQ [dB]	Average RSRQ [dB]	Maximum RSRQ [dB]
0,0	-9,3	-7,8	-6,8
0,8	-8,7	-7,3	-6,6
1,6	-7,8	-7,1	-6,4
2,4	-10,1	-8,1	-6,8
3,2	-7,0	-6,9	-6,8
4,0	-8,6	-7,4	-6,7
4,8	-7,8	-7,1	-6,5
5,6	-8,9	-7,5	-6,3
6,4	-7,1	-6,5	-6,0
7,2	-7,9	-7,2	-6,6
8,0	-7,9	-6,9	-6,4
8,8	-10,8	-8,3	-6,3
9,6	-9,3	-7,4	-6,4
10,4	-7,4	-6,9	-6,3
11,2	-8,3	-7,2	-6,5
12,0	-7,9	-7,1	-6,1
12,8	-6,6	-6,6	-6,5
13,6	-6,6	-6,4	-6,3
14,4	-6,9	-6,7	-6,4
15,2	-8,6	-7,2	-6,4
16,0	-9,2	-7,7	-6,3
16,8	-6,8	-6,4	-6,1
17,6	-8,2	-6,7	-6,1
18,4	-9,6	-7,9	-6,4
19,2	-7,4	-6,7	-6,3
20,0	-9,1	-7,1	-6,1
20,8	-9,1	-7,1	-6,4
21,6	-7,5	-6,6	-6,2
22,4	-10,3	-7,2	-6,0
23,2	-10,3	-7,7	-6,2
24,0	-8,1	-6,6	-6,1

Appendix B - Drone usage

1 Warnings & Notes

- Rotor blades are super hard, sharp and strong carbon fibre. Be careful around them!
- Always power on the Radio Controller before the copter!
- Balance the copter with the batteries by moving their weight point and lifting the copter up
- Never arm and start flying before GPS lock = green light. It might lead to a fly away
- Start always on an even ground. The drone calibrates itself at arming point.
- LiPo batteries are very dangerous if they start burning. The fire is practically impossible to put out
- NEVER use the batteries if punctured or puffed
- Burning hot battery after flight or recharge means something's wrong, ask help from EuroRC
- Power output on the power supply should be max 18V! Higher might break Batteries shouldn't be stored charged! Long-time storing should be done with 3.8 V
- Always select LiPo mode from the recharger and check the voltage/current
- Check the screw tightness every now and then, especially for the rotors with a 2.5 mm hex key.
- Always detach the rotors before powering the copter indoors

2 Batteries

The drone uses two 6S 22.2 V batteries. There's some rules about them.

Recharging batteries

1. Before switching the power supply on, attach all the cables: Power cable to the power, Charger to power, two batteries to the charger with the small balancer cables to the taps
2. Set Power output to ~16 V
3. Switch everything on starting from the power
4. Select LiPo mode
5. Check that final voltage is set to 22 V (6S) for the big main batteries and 11.1 V (3S) for the small imbal battery
6. Check that recharge rate is set to 1 C which is 10 A for the main batteries and 1.2 A for the gimbal battery
7. Start with a long press on "start"
8. Wait for recharging, it beeps when ready
9. Detach batteries
10. Recharge more batteries or switch the equipment off and unplug the cables

11. Use a rubber band to tie the balancing cable to the battery so the rotors won't be hit them

2.1 Storing batteries

1. Discharge the batteries with the drone to 3.8 V
 - a. Possible with the recharger but shouldn't be used
2. Store in cool, dry and dark place

2.2 Measuring the voltage

Attach the battery monitor to the balancing cable with black side to the left and red cable to the middle. There's also instructions in the bottom of the monitor

2.3 Attaching batteries

1. Make sure the controller is on, left stick (gas) is at zero, right stick is in the middle, and all the switches are in the basic state (pointing away from you).
2. Put both batteries on to their places. Make sure the drone is balanced by lifting it up. Adjust & repeat. Bind with straps.
3. Plug one big cable first keeping your hands out of the rotor blades. Wait a moment for the FC to calibrate. Attach the other one.
4. Attach the gimbal battery cable on the small battery

3 Starting up

- Always keep your hands out of the rotor blades. Some say they cut like Ganzo knives.
- Always keep the copter away from people
- Always wait for GPS lock which means green blinking light. This will reduce the likelihood of the drone escaping

3.1 The steps needed only for LTE are marked in GREY.

1. Prepare the PC
 - a. Start-up
 - b. Disable WLAN
 - c. Attach LTE-stick
 - d. Connect to the LTE network (or verify other connection).
 - e. Update the DNS (use dyndns.bat on the desktop).
 - f. Attach the gamepad
 - g. Start Mission Planner
 - h. Wait ~5min
2. Launch Netbeans and start the pingrssi-server.py (or run it with bat)
3. Start RC
 - a. Make sure that left stick is 0 and right in the middle
 - b. Make sure all switches are in the default position (away from you)
4. Leave RC on the ground and go to the copter

5. Put batteries on their places, make sure no cables will go to the rotor blades
6. Balance the drone
7. Attach one of the batteries carefully hands out of the reach of the blades.
8. Wait a while for the FC to calibrate itself, attach the other battery
9. Wait for the green (GPS) light on the led
10. Wait until the orange dim LED on the top stays on steadily (shadow it to see).
 - a. If it takes over 5 min, use the big black button to halt the RasPi, detach the white power plug under, and reattach. Wait again 5min.
11. When orange LED is steady, use Mission Planner to connect with UDP 57000. If the connection does not work make sure that
 - a. PC is connected to NetLeap
 - b. Orange LED on the copter is not blinking
 - c. You have updated the DNS on PC
12. Arm by pushing the red light button for couple of seconds
13. Go to the controller ~ 5 m away
14. Finalize arming by holding the throttle/yaw at right down until it beeps
15. Ready to fly
16. The controller will auto-disarm itself if no commands are issued for 15 s

4 Flying

- Practise a lot before doing complex flight. Rotating the drone might mess your sense of direction completely, leading into a crash

4.1 Lift-off and training

1. Start adding throttle slowly
2. Be careful around 50%, as the drone starts to lift. At this point it will most likely tilt to some direction. Compensate it with the right stick while adding more throttle
3. Raise the drone to around 5 m high so there won't be "ground effect" anymore
4. In the beginning use only right stick to control the direction, while using left stick to only control the height. When you are comfortable with this, you can move on to the next step
5. Now you can start rotating the drone. Use the right stick to rotate 90 degrees. Remember that the directions will be changed. Now forward is to right, right is towards yourself etc.
6. Make sure you are familiar with the different rotations and directions. You need to be able to control it in an emergency situation exactly where you want.
7. Now you can start activate different flight modes and trying combining both sticks, for example do circling.

4.2 Flying with LTE

1. Follow the steps on Appendix C -5 Setting up the joystick
2. Make sure you have done every step for the GREY LTE part on section 3
3. Make sure you have GPS lock = FC status LED is green
4. Check that the values are being updated on the Mission Planner
5. Follow the steps above in 4.1 until the step 3.
6. Switch the “Loiter” mode on. At the time of this thesis it has been set up to “high position / towards the pilot” on the “Switch C” on the RC. The copter should stay at the same position by itself
7. Open the “Actions” tab at the lower left on the Mission Planner
8. Click the “Joystick” button
9. Click “Enable” on the “Joystick” window
10. Now you can use the gamepad for flying

5 Programming The Flight Controller

Check manual at <http://copter.ardupilot.com/wiki/introduction/>

6 Programming The Radio Controller

Check the paper manual or <http://manuals.hobbico.com/fut/10j-manual.pdf>

Appendix C - LTE Setup

These instructions have been written for the equipment mentioned as examples. Thus, they might have unnecessary parts or missing important ones when different equipment is used.

1 Parts needed

- Raspberry Pi, these instructions are for the B+ with Raspbian
- LTE USB dongle, e.g. Telewell LTE/4G/3G.
- Monitor with HDMI
- UART-ETH adapter, e.g. Lantronix XP100100-05R
- Short ETH cable
- Expendable USB and Pixhawk telemetry cables
- 5V > 2A power source, e.g. the 5V5A BEC on the drone
- Lots of small cables, solder
- Temporary switch

2 Raspberry Pi setup

1. Install Raspbian in your preferred way.
2. The default username/password are pi/raspberry

2.1 Connecting USB & Power cables to RasPi

1. Cut the USB Cable
2. Solder cables in the following order, verify the colours before attaching. USB numbers are from up to down, when the ports are pointing to right (and all text readable/right way):
 - a. +5 V (Red) – PP1 or USB 1
 - b. Data - (Green) – USB 2
 - c. Data + (White) – USB 3
 - d. Ground (Thin Black) – PP1 or USB 4
 - e. Ground (Thick Black) – Ground leg
3. Get convenient power connector with some cable, so it's easy to (un)plug into power when needed.
 - a. Do the next steps shown also in the Figure 20 below
 - b. Solder + (Red) to PP1 or to F1 "left" leg (next to PP1)
 - c. Solder – (Black) to PP3
 - d. Solder the other end to the 5V BEC on the copter

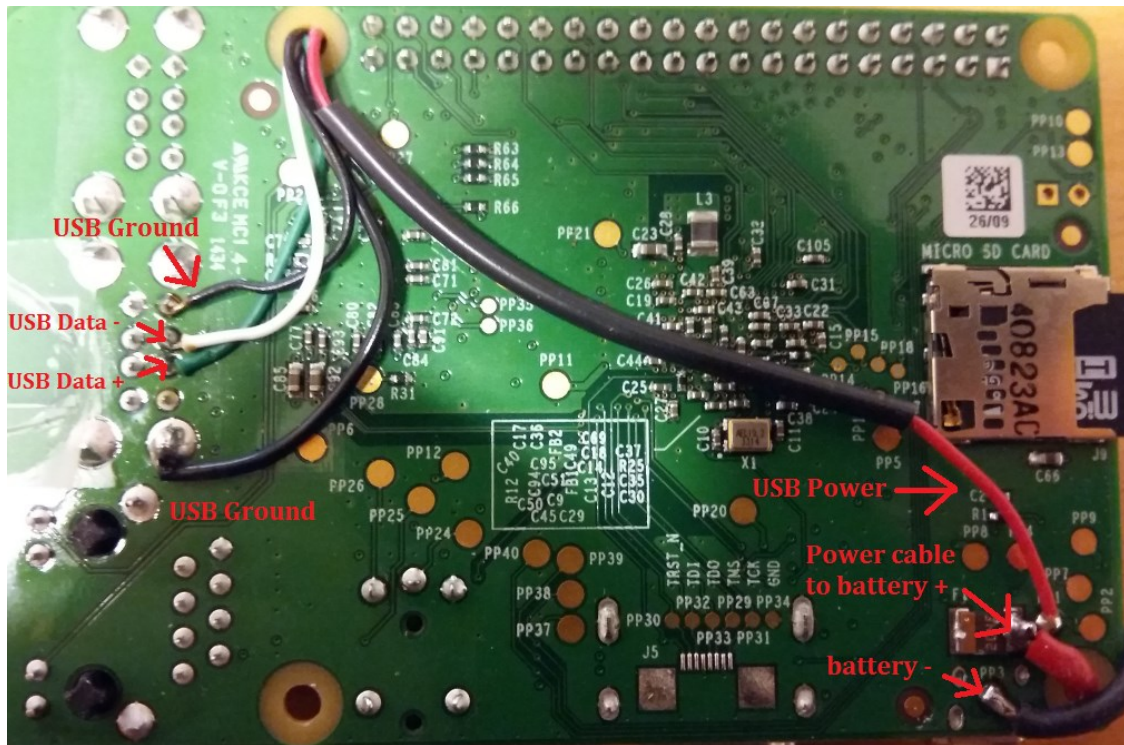


Figure 20. Connections on the bottom of the RPi

2.2 Installing the USB Modem

1. Plug in the dongle.
2. Run **"lsusb"**. This shows the dongle vendor and product IDs, e.g. **19d2** and **0413** for the TeleWell dongles
3. Create a file to **/etc/usb_modeswitch.d/** named by the IDs, e.g. **19d2:0413** and add following:

```
###Telewell TW-LTE v1###
DefaultVendor= 0x19d2
DefaultProduct= 0x0413
TargetVendor= 0x19d2
TargetProduct= 0x0412
MessageEndpoint= not set
MessageContent="5553424312345678240000008000006850000002400000000000000000000000"
NeedResponse=0
ResponseEndpoint= not set
Interface=0x00
CheckSuccess=20
```
4. Now you must edit **/lib/udev/rules.d/40-usb_modeswitch.rules** by finding any ZTE modem and changing the product ID to 0413. Remember to match the vendor ID also.
5. For some reason this isn't enough, but the modem needs to be initialized twice. Thus you need to add **"usb_modeswitch -W -I -c /etc/usb_modeswitch.d/19d2\:0413"** to **/etc/rc.local**. This will run the script for a second time during the boot.
6. The modem should be set up and after reboot it should show on **"lsusb"** with ID **19d2:0412**, in **/dev/** as **cdc-wdm0** and with **ifconfig** as **wwan0**.
7. Now you can use your favourite software to connect to the network.

2.3 Connecting at startup

Next we will explain one, not recommendable as it is complicated, way to connect to the Internet. This uses “**uqmi**” which has a complicated installation. As prerequisite “**sudo apt-get install cmake autotools**”

1. Use “**sudo apt-get install libjson0 libjson-dev**” to install json libraries. You can test if this is enough like it should be and skip the next step.
2. Install and compile **json-c** from **git**.
 - a. `cd ~`
 - b. `git clone https://github.com/json-c/json-c.git`
 - c. `cd json-c`
 - d. `autoreconf -i`
 - e. `./configure --prefix=/usr`
 - f. `make`
 - g. `make install`
 - h. `sudo ln -sf /usr/include/json-c /usr/include/json`
3. If previous steps succeeded, you can install **libubox** from **git**
 - a. `cd ~`
 - b. `git clone git://nbd.name/luci2/libubox.git /opt/git/libubox`
 - c. `cd /opt/git/libubox/`
 - d. `cmake CMakeLists.txt -DBUILD_LUA=OFF`
 - e. `make`
 - f. `sudo make install`
4. Then git, compile and install **uqmi**
 - a. `cd ~#`
 - b. `sudo git clone git://nbd.name/uqmi.git`
 - c. `cd uqmi`
 - d. `sudo cmake CMakeLists.txt`
 - e. `sudo make install`

2.4 Making the UDP redirection

1. You can use **socat** or any script, for example `upd_redirect http://brokestream.com/udp_redirect.html`, to route the UDP packets
2. `sudo apt-get install socat`
3. Add “`socat UDP4-RECVFROM:14450,fork UDP4-SENDTO:***IP***:14450 &`” to `/etc/rc.local`, where the `***IP***` should be the controlling PC IP, DNS name or similar

3 Ethernet-Serial module setup

Needed:

- ETH-Serial module, for example Lantronix XPort
- Extra Pixhawk telemetry cable
- ETH-cable
- Lantronix device installer from http://ltxfaq.custhelp.com/app/answers/detail/a_id/644

- This guide uses Windows for the configuration. It can be done also by telnet and other options, see the product manual

3.1 Hardware configuration

1. Cut the telemetry cable from the middle, make sure that it will be long enough to use.
2. Attach the data cables to the module. Unfortunately power cannot be drawn from the Pixhawk as it would give 5V instead of the required 3,3V. Leave the power cable ends open for now
3. Connect the power cables to a 3,3V power source, for example RPi GPIO as shown in the Figure 21 below
4. Connect the ETH-cable from a computer to the module. I do not recommend using RasPi for this, as the configuration is the easiest to do with a proper computer with a GUI
5. Now there should be only a green light lit up on the XPort
 - Check the cables and reconnect the power if not or there's also an orange light
6. Connect the telemetry cable to the "Telem 1" port on the Pixhawk

3.2 Software configuration

1. Set your PC LAN IP as 192.168.1.1. Subnet can be the default 255.255.255.0.
2. Open up the device installer.
3. Make sure, that only "local area connection" is selected in the *options*.
4. Now you can search for devices.
 - a. If this does not show anything, use the *assign IP* and use the MAC address written on top of the module.
5. Then right click and open the web setup.
6. Username/password are ""/"" (blank).
7. On network tab
 - a. Set static IP with "Use the following IP configuration" and set it as follows
 - i. IP: 192.168.1.2
 - ii. Subnet: 255.255.255.0
 - iii. Gateway: 192.168.1.1
 - iv. DNS Server: 0.0.0.0
 - b. Also make sure that "Auto negotiate" is selected.
 - c. Press OK
8. On "Serial Tunnel" – "Hostlist"
 - a. Set 192.168.1.1 | 14550 as No. 1 and press OK
9. On "Channel 1"
 - a. "Serial Settings" set
 - i. Protocol: RS232
 - ii. Baud Rate: 57600
 - iii. Data Bits: 8
 - iv. Flow Control: CTS/RTS (Hardware)
 - v. Parity: None
 - vi. Stop Bits: 1

- vii. OK
 - b. "Connection"
 - i. Protocol: UDP
 - ii. Datagram Type: 01
 - iii. Local Port: 14550
 - iv. Remote Port: 14550
 - v. Remote Host: 192.168.1.1
 - vi. OK
- 10. Now it's time to "Apply Settings", wait the module to reboot, and remove the power.

4 Scripts

4.1 Halt switch

- Attach the cords as shown on the Figure 21 next page
 - The power cord to GPIO pin 1
 - The switch on cord to GPIO pin 4
 - The ground cable from the same button leg as "switch on" to the GPIO pin 5
- Create and run the following script with Python 2 and make it run at startup

```
# Import the modules to send commands to the system and access GPIO pins
from subprocess import call
import time
import RPi.GPIO as gpio

gpiopin = 7 # Set the GPIO pin used for the interrupt

# Define a function to keep script running
def loop():
    while True:
        time.sleep(1)
# raw_input()

# Define a function to run when an interrupt is called
def shutdown(pin):
    print("Halt button was pressed, HALTING!")
    call('halt', shell=False)

gpio.setmode(gpio.BOARD) # Set pin numbering to board numbering
gpio.setup(gpiopin, gpio.IN) # Set up gpiopin as an input
gpio.add_event_detect(gpiopin, gpio.RISING, callback=shutdown, bouncetime=200) # Set up an interrupt to look for button presses

loop() # Run the loop function to keep script running
```

4.2 LED light

1. Attach the LED cables as shown on the Figure 21 below
 - a. + cable to the GPIO pin 22
 - b. - cable to the GPIO pin 20
2. Create a python script with the following content, and make it run automatically at startup to see when the LTE connection is up

```
import RPi.GPIO as gpio
import os, time, sys
```

```

gpio.setmode( gpio.BOARD )
gpio.setup( 36, gpio.OUT )
result = 1
address = "8.8.8.8"
i = 0

while (result <= 0) and (i < 30) :
    result = os.system("ping -q -c 1 -w 1 " + address + " > /dev/null 2>&1")
    print ("Ping result to 8.8.8.8 was: " + str(result) )
    gpio.output( 36, True )
    time.sleep(0.5)
    gpio.output( 36, False )
    time.sleep(0.5)
    gpio.output( 36, True )
    time.sleep(0.5)
    gpio.output( 36, False )
    time.sleep(1)
    i = i + 1

```

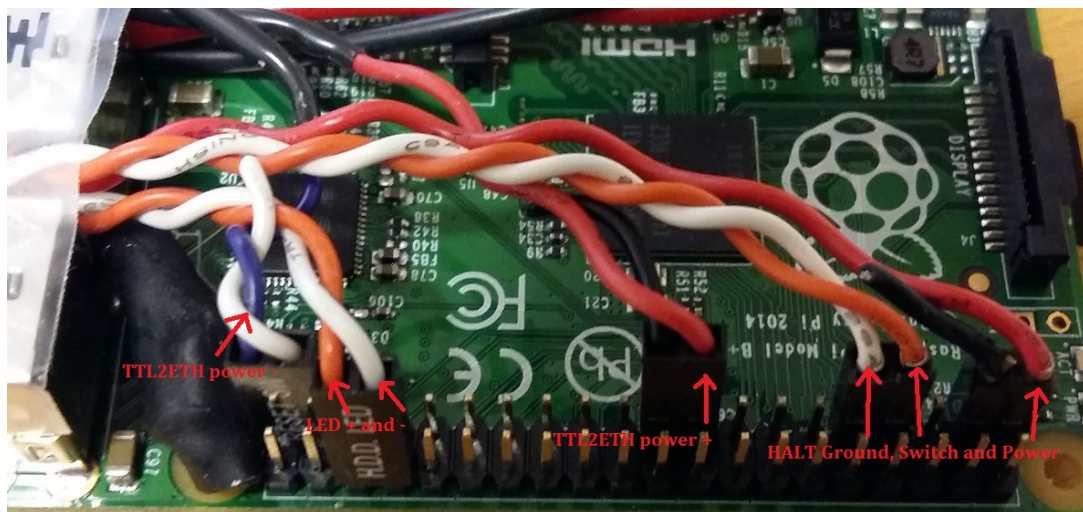


Figure 21. GPIO connections on the RPi

3. Create a python script with the following content, and make it run automatically at startup to see when the Ground Control Station laptop DDNS has been updated

```

import RPi.GPIO as gpio
import os, time, sys

gpio.setmode( gpio.BOARD )
gpio.setup( 36, gpio.OUT )
result = 1
address = sys.argv[1] #"masema.mooo.com"

while result <= 0:
    gpio.output( 36, True )
    result = os.system("ping -q -c 1 -w 1 " + address)
    print result
    time.sleep(1)
    gpio.output( 36, False )
    time.sleep(1)

gpio.output( 36, True )
exit()

```

4.3 Updating the IP to “freeDNS.afraid.org” DDNS service as “kopteri.moood.com”

- Create a script for the DDNS update. Note that you can get the link from the freeDNS.afraid.org with the username XXX and password XXX

```
wget -O - --no-check-certificate
https://freedns.afraid.org/dynamic/update.php?YWFQeWlZVVg0M0lOY29lenQ5c2c6MTM2OTkwODc= > ~/dyndns.log
```

4.4 Starting everything at boot

- Add following code to the rc.local file.

```
#!/bin/sh -e

echo "Starting LTE"
/home/pi/startupscripts/lte_start.sh
sleep 5

HOST=`hostname -l`
DEST="masema.moood.com"

if [ "$HOST" ]; then
    echo "$HOST"
fi

echo "Starting halt-button script"
python /home/pi/startupscripts/interrupt_halt.py &
echo "Making sure that connection is up by pinging 8.8.8.8"
python /home/pi/startupscripts/connup_LED.py
echo "Updating DYNDNS (kopteri.moood.com)"
/home/pi/startupscripts/dns_update.sh
echo "Making sure GCS DNS has been updated"
python /home/pi/startupscripts/ready_LED.py "$DEST"
echo "Starting UDP Redirect. Must be after GCS DNS has been updated."
/home/pi/startupscripts/udp_start.sh

exit 0
```

5 Setting up the joystick

1. Attach the joystick onto USB
2. Open up Mission Planner
3. Open “Actions” tab in the low left
4. Click “Joystick” button
5. Select correct Joystick from the drop down list on the upper part
6. Use the “Auto Detect” button to select up right axis. The same layout with the RC is recommended
7. Make sure that the sticks are working the right way. You might need to “reverse” the Throttle
8. Add buttons to CH5-8. These can be used for functions such as arm/disarm, flight mode, Return to Home etc.
9. USE the “Save” BUTTON!
10. Follow the instructions in the Appendix B -4.2 Flying with LTE for flying